Elements of Physical Science

Das Gupta and Banerjee

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ELEMENTS
OF
PHYSICAL SCIENCE

[*CLASS X*]

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SYLLABUS FOR CLASS X

Physical Science

(Common to both Physics & Chemistry)

Page limit :

Common to both Physics & Chemistry	—20 Pages
Physics	—42 "
Chemistry	—52 "
Total	—114 "

1. Atomic structure of matter. Elementary ideas of the planetary model of the atom. Structure of the nucleus. Mass, size and charge of electron, proton and neutron. Isotopes, Atomic numbers, atomic weight and mass number. (Non-mathematical treatment. Elementary ideas with illustrative examples) ...[10 pages]

2. Properties of gases—pressure and temperature. Boyle's and Charles' laws. Avogadro's hypothesis. Avogadro's number. Molecular weight. Brief mention of the motion of gas molecules and the dependence of pressure and temperature on such motion (very elementary non-mathematical discussion) ...[10 pages]

Physics - 42 pages

1. Sources of sound : Sound produced by vibration. Propagation of sound. Necessity of a medium for sound. Frequency and pitch. Velocity of sound. Reflection of sound. Echo. Musical sound and noise. Ultrasonic waves and their applications. [14 pages]

2. Electric current : E. M. F. of a cell. Ohm's law and resistance (no sums). Heating effect of current and Joule's law.

Action of current on a magnet. Ampere's swimming rule. Action of a magnet on a current. Barlow's wheel. Application in case of a Motor. Electromagnetic induction. Principle of dynamo. ...[15 pages]

3. Electromagnet. Simple principle of a telephone receiver. ...[5 pages]

4. Conduction of electricity through a gas at a low pressure. Elementary idea of Cathode rays. X-rays. ...[8 pages]

Chemistry—52 pages.

1. Molecules and atoms. Dalton's atomic theory. Periodicity of elements ; classification of elements in periodic table (elementary ideas) : Electrovalency and Covalency ...[8 pages]

2. Atomic weight, Molecular weight, Molar volume, Gram atomic weight, Gram molecular weight. ...[4 pages]

3. Simple methods of preparation, simple properties and typical reactions of HCl, H_2SO_4 (contact process), and HNO_3. [10 pages]

4. Sources and uses of Carbon, Sulphur, Phosphorus—Boron and Allotropy of carbon and phosphorus. ...[4 pages]

5. Nature, sources and uses of : Glass, caustic soda, washing soda, common salt, bleaching powder, quick and slaked lime. Copper sulphate, ammonium sulphate, soap, petrol, Kerosene, Rectified spirit ; Methylated spirit. ...[6 pages]

6. Source, elementary properties (physical and chemical behaviour towards air, water, dilute acids and alkalies) and uses of Aluminium, Magnesium, Zinc, Iron, Copper, Lead, Mercury : Elementary idea of Alloys and Amalgams. [...8 pages]

7. (*a*) Organic compounds—scope and variety. Its role in life processes—Nature and elementary classification of organic compound—Linkage in Carbon compounds—its difference from inorganic compounds. ...[8 pages]

(*b*) Sources and uses (preparation and properties excluded) of the following : CH_4, C_2H_4, C_2H_2 ; Chloroform, Ethyl alcohol, Vinegar, Glycerol, Glucose, Urea, Benzene, Phenol, Napthalene. ...[4 pages]

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COMMON TOPICS

(FOR CLASS *X*)

CHAPTER ONE

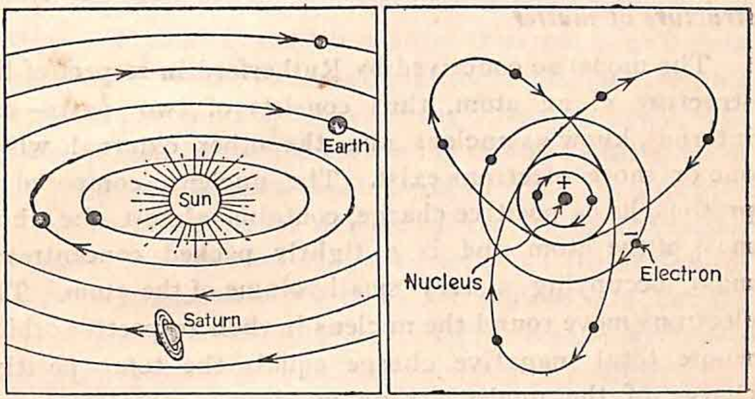
ATOMIC STRUCTURE

1·1 Atomic structure of matter :

Philosophers of ancient time are known to have expressed curiosity about the structure of matter and gave various opinions about it. *Kanad*, the ancient Indian sage, was of opinion that matter consists of very small particles. As far back as the 6th century B C., the Greek Philosophers opined that matter is composed of discreet, discontinuous and tiny particles. They said that if you stand near a sea-shore, the shore will appear continuous. But if you take a handful of sand from the shore, you will see that it consists of thousands of discreet and discontinuous sand particles. In the same way, a piece of matter may apparently seem to be continuous but in reality it consists of tiny particles. The word **'atomos'** according to Greek vocabulary, means indivisible. Hence they called the tiny particles of matter 'atoms'. But these are all conjectures of ancient people—not substantiated by actual experimentation. They did nothing more and left the idea vague. In the early part of the nineteenth century, John Dalton, a noted English chemist, first developed a scientific theory regarding the structure of matter, partly from the ancient guess-work and partly from some modern experimental results. It is known as Dalton's atomic theory according to which every substance is composed of very minute, indivisible particles, known as atoms. [For details, see art. 1·2, chemistry part.]

Till the end of the nineteenth century, scientists believed that atom is the smallest, indivisible state of matter, that atoms cannot be subdivided and that two or more atoms combining together produce a molecule and two or more molecules produce a piece of matter. But during the last decade of the nineteenth century, Sir J. J. Thomson, Crookes, Lenard and others carried out some experiments with electric discharge through gases at low pressure [*See Art. 4·2, 4th Chapter Physics Section*] and discovered a particle which is about 1836 times lighter than the atom of the lightest element 'Hydrogen.' It, at once, indicated that the ideas of the scientists about the atom being the smallest, indivisible particle are not correct. Atoms are divisible and still smaller particles are available by breaking up an atom. The most significant characteristics of these tiny particles are : (*i*) they are charged with negative electricity and (*ii*) they are all alike—*i.e.*, from whatever atoms they are collected, they have identical mass, diameter, electrical charge etc. These particles came to be called **electrons.** If electrons are collected from hydrogen atom, oxygen atom, chlorine atom or from any compound, they will be all identical in all respects. Since electron enters into the constitution of all atoms, it is considered by the scientists as a *fundamental particle in the structure of matter*.

If a complete atom obtained either from an element or from any other substance, be examined in respect of its electrical charge, it will be found to have no charge, either positive or negative ; a complete atom is always neutral but the electrons obtained from an atom show negative charge. It means that in an atom equal amount of positive charge must be present somewhere—otherwise how can an atom be electrically neutral ? How and where does this positive charge exist in an atom ? After a series of carefully designed experiments and calculations, Lord Rutherford, the eminent British Physicist, told that the positive charge was concentrated in a very small space at the centre of an atom. To this centralised positive charge, he gave the name '**nucleus**' He said that the structure of an atom is like the structure of the solar system. The solar system consists of a central Sun with planets like the Earth. the Saturn, the Jupiteretc. revolving round it in their respective orbits An atom is very similar to this ; it has a central nucleus with electrons revolving round it in their respective orbits [Fig 1] The nucleus plays the role of the sun, while the electrons those of the planets. As the mass of the sun is very great in comparison with the mass of any planet, so in an atom, the mass of the nucleus is very great compared to the mass of an electron. As a matter of fact, *almost the whole mass of an atom is concentrated in its nucleus.* The diameter of an atom is about 10,000 times greater than that of its nucleus. We can, therefore, say that almost the whole of the inside of an atom is vacuous just as almost the whole of the inside of solar system is vacuous. As the sun exerts gravitational attraction upon each planet,which keeps the planet moving steadily in its orbit, so in an atom, the positively charged nucleus exerts electrical force of attraction upon each electron, which keeps it in its orbit.



Solar System Fig. 1 Neon Atom

An atom of the simplest element hydrogen is found to contain only one electron Its nucleus, therefore, should have positive charge equal in amount to the negative charge of an electron because a complete atom is always electrically neutral. This nucleus of hydrogen atom came to be known as **Proton**. So, a proton and an electron have equal amount of charge but their nature is opposite, protons having positive charge while electrons negative charge. But their masses are not equal, protonic mass being about 1836 times the electronic mass. As proton enters into the constitution of nuclei of all atoms, *it is regarded, like an electron, a fundamental particle in the structure of matter.*

The model so conceived by Rutherford in respect of the structure of an atom, thus consists of two parts—one internal, know as nucleus and the other external where one or more electrons exist. The nucleus, composed of protons, has a positive charge, contains almost the whole mass of the atom and is a tightly packed concentrated mass, occupying a very small volume of the atom. The electrons move round the nucleus in their respective orbits, whose total nagative charge equals the total positive charge of the nucleus, thus making a complete atom always electrically neutral. Difference in the number of electrons in atoms attributes difference in physical and chemical properties of atoms and this is the reason why we see varieties of substances around us.

This porton-electron model of atomic structure is not without defects. Very soon its short-comings came in the forefront. A discussion of the structure of atoms of different elements will make it clear. After the simplest element hydrogen, comes the inert gas helium, whose atom is four times heavier than a hydrogen atom. So a helium atom should contain four protons in its nucleus. On the other hand, from various experiments it came to be known that a helium atom contains two extranuclear electrons How will the charges of two extra protons be balanced ? This discrepancy becomes more and more acute in the case of heavier elements. For example, the nucleus of a carbon atom should have 12 protons while only 6 electrons exist outside the nucleus. Thus, charges of 6 protons remain unbalanced. The heaviest element uranium is found to have 238 protons in the nucleus, while only 92 electrons revolve round the nucleus. So, charges of (238−92) = 146 protons are yet to be balanced. In all these cases, in order to balance the charges of extra protons and to give a complete atom a neutral character, the scientists agreed to accept the existence of requisite number of electrons *in the nucleus*. The nucleus of helium atom, thus, contains 2 electrons, carbon atom 6 electrons, uranium atom 146 electrons and so on. Electrons being exceedingly small in mass, will not contribute, by their presence, anything to the mass of the nucleus and hence to the mass of an atom, but will give an atom its much-needed neutral character. So, the model of atomic structure now stands as follows : the nucleus of an atom is composed of electrons and protons and outside nucleus there are only electrons. In the case of hydrogen atom only, the nucleus does not contain any electron ; it is composed of a proton only.

But this model, too, did not last long. A number of serious difficulties cropped up. Finally, after the discovery of isotopes it appeared almost certain that electrons connot exist inside the nucleus for the following reasons. The isotopes (*isos* = same, *topos* = place) of a given element are such substances which have precisely the same physical and chemical properties as those of the element but have different atomic weights. For example, neon has two isotopes ; their atomic weights are 20 and 22 but their physical and chemical properties are identical. As a result, they cannot be separated from each other by easy chemical means. Now, identity of physical and chemical properties between an element and its isotopes necessarily means that their atoms have equal number of extranuclear electrons because these electrons are responsible for physical and chemical behaviour of an atom. Consequently these atoms should have an equal number of protons, too. How then, can we account for the difference in their atomic weights ?

These difficulties were solved in 1932 when another fundamental particle was discovered. This particle was discovered by Prof. James Chadwick who gave the name **'Neutron'** to this new particle. Neutron is a neutral particle having mass almost same as that of a proton. Almost immediately after the discovery of neutron, scientists turned their attention to the proton-neutron theory of the structure of the nucleus and rejected the proton-electron theory According to this theory, the number of extra-nuclear electrons is equal to the number of protons in the nucleus and the extra electrons in the nucleus according to the proton-electron theory are to be replaced by equal number of neutrons. Thus, in an atom of helium there are 2 extra-nuclear electrons revolving round a nucleus composed of 2 protons and 2 neutrons, in lithium atom, there are three protons and four neutrons in the nucleus and 3 electrons outside, (Fig. 2) in a carbon atom, there are 6 extra-nuclear electrons, and 6 protons and 6 neutrons in the nucleus, in uranium atom, 92 electrons outside the nucleus and 92 protons together with (238 − 92) = 146 neutrons in the nucleus Only hydrogen atom does not contain neutron. Regarding the structure of an isotopic atom, it is said that their atoms will contain same number of electrons and protons but the number neutrons in their nuclei would be different. This would give different atomic weight but because of identical number of extra-nuclear electrons, their properties will precisely be the same. For example, in the case of neon isotopes of

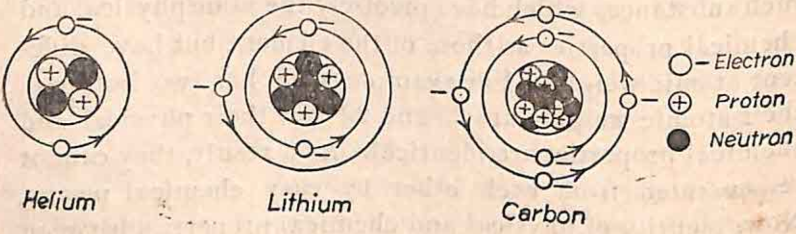
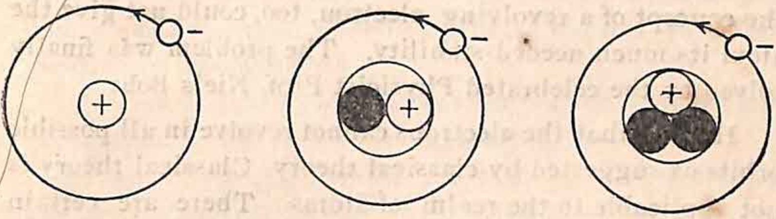


Fig. 2

atomic weights 20 and 22, each atom of the isotopes will have 10 electrons and 10 protons but in the nucleus of the first, the number of neutrons is 10 while in the second, the number is 12. Fig. 3 shows the atomic structure of the isotopes of the lightest element hydrogen. Ordinary hydrogen atom (${}_1H^1$) does not possess any neutron in its nucleus, deuterium atom (${}_1H^2$) has one neutron in its nucleus and the tritium atom (${}_1H^3$) 2 neutrons in its nucleus. But the number of protons and electrons in each case is the same. As a result, their physical and chemical behaviours have become identical but atomic weights different.



Hydrogen(${}_1H^1$) Deuterium (${}_1H^2$) Tritium (${}_1H^3$)

Fig 3

It has been mentioned earlier that difference in the number of electrons attributes difference in physical and chemical properties of atoms and this is the reason why we see varieties of substances around us. But the question is how are these electrons in an atom situated ?

Take the case of the simplest element hydrogen. Its atom consists of an electron and a proton According to the laws of electric charge, attraction will take place between them because they carry equal but opposite charges. As a result, electron will fall upon the proton and the structure of the atom will collapse. But in reality, we find hydrogen to be quite stable. To remove this discrepancy, Rutherford told that the electron is revolving round the nucleus in an orbit just like the planets revolve round the sun. The attractive force between the proton and the electron will be balanced by the centrifugal force of the electron obtained due to rotational motion But this gave rise to another difficulty. According to classical electro-dynamics, a charged particle like electron, when revolving, will continuously radiate energy and consequently the radius of its orbit will gradually shrink, making the electron finally coalesce with the proton. So, the concept of a revolving electron, too, could not give the atom its much needed stability. The problem was finally solved by the celebrated Physicist Prof. Niels Bohr

He told that the electrons cannot revolve in all possible orbits as suggested by classical theory. Classical theory is not applicable to the realm of atoms There are certain privileged orbits, according to Bohr's theory, where electrons can revolve without any radiation of energy. One or more such orbits constitute an electron shell and he named them as K. L. M. shells, etc. The maximum number of electrons that a particular shell can contain is fixed. For example, the shell nearest to the nucleus—the *K*-shell can contain, at best, two electrons and not more than that. The next shell—the *L* shell—can contain 8 electrons, the *M* shell 18 electrons, etc. If a particular shell contains all the electrons that it can possibly contain, the shell is said to be complete or saturated. These numbers may appear to be haphazard at first sight but they are not so If the shells be numbered as 1, 2, 3, 4 etc. then the square of the number of any shell multiplied by 2 will give the greatest number of electrons that the shell can contain.

Now let us come to the case of hydrogen atom. It has one electron only. It goes without saying that this single electron of the hydrogen atom resides in the *K*-shell. Next comes helium atom which has two electrons. The *K*-shell cannot contain more than 2 electrons. Hence 2 electrons of helium atom revolve in the *K*-shell which therefore becomes complete. Next comes lithium atom having three electrons Two of these electrons complete the K-shell and third goes to L-shell, which can contain, as we have seen earlier, 8 electrons in the maximum. In this way, if we come to neon atom, we find that it contains 10 electrons. Out of these 10 electrons, two go to complete the K-shell and the remaining 8 electrons go to complete the L-shell. So, the first two shells of the neon atom are complete just as the first shell of the helium atom is. Next comes sodium atom which requires M-shell to provide position for its electrons.

It may be mentioned in this connection that chemical properties of an atom are mainly determined by the electrons in the outermost orbit of it. These electrons are known as 'valence electrons.' We have seen that the atoms of gaseous elements like helium, neon, argon, etc. have respectively their K-shell, L-shell, M-shell complete. There is no vacancy in those shells which means that these atoms have no valence electrons. Curiously enough, their chemical properties are also similar—each one of them is an inert gas. Again, atoms of lithium, sodium potassium, etc have one valence electron each and this valence electron of these elements resides respectively in K, L, M shells. There is also striking similarly in their chemical properties.

In this way, the theory advanced by the joint effort of Rutherford and Bohr regarding structure of an atom gave consistent results in all respects and came to be accepted by all.

1·2 Atomic weight, mass number and atomic number :

How small is an atom ? How light it is ? It goes without saying that atoms and molecules are exceedingly small—so small that even a very powerful microscope will not reveal their existence. Calculation shows that there may be 3×10^9 atoms of hydrogen in a space whose length, breadth and height are each only 1 centimeter. If the weight of an atom of hydrogen be calculated, the figure comes out as $1{\cdot}67\times10^{-24}$ gram !

Such small figures are very inconvenient to deal with. Scientists have, therefore, devised another method of calculating weights of different atoms. They take atom of a particular element as a standard and express the weights of other atoms of other elements in comparison with that standard. The chemical system of calculating *atomic weights* adopts as a standard 16 for the atomic weight of oxygen and the atomic weights of all other elements are then stated in terms of O=16 as the standard. So, the at wt. of an element

$$=\frac{\text{the wt of an atom of the element}}{\frac{1}{16}\text{th of the wt. of an } O_2 \text{ atom}}$$

Thus, the atomic weight of hydrogen is **1·00813**, that of helium **4·00387**, that of aluminium **26·99014**, etc. This means that an atom of hydrogen is about $\frac{1}{16}$ times heavier than an oxygen atom. Similary a helium atom is $\frac{4}{16}$ or $\frac{1}{4}$ times and an aluminium atom about $\frac{27}{16}$ times heavier than an oxygen atom.

Now, the **mass number** of an atom denotes the integer nearest to the value of the atomic weight of that atom. Thus, the mass number of hydrogen atom is **1**, that of helium **4**, of aluminium **27**, etc. The mass number also represents the total number of protons and neutrons in the nucleus of an atom. For example, the mass number of helium is **4** but the helium nucleus is composed of two protons and two neutrons *i. e.*, of 4 particles. In the same way, the nucleus of aluminium atom contains 27 particles, carbon atom 12, uranium atom 238, etc. Ordinarily, the mass number is denoted by the letter *A*. So we can write,

A=number of protons+neutrons in the nucleus

On the other hand, the **atomic number** of an atom denotes the number of electrons outside the nucleus of a neutral atom. It has got another important significance. Long ago, the celebrated Russian Chemist Mendelejeff showed that if the chemical elements are arranged in order of their atomic weights, they show a regulary occurring sequence in their chemical properties. Such an arrangement is known as the *periodic table.* Interestingly enough, the atomic number of an element coincides with its position in the periodic table. For example, the first position in the periodic table is occupied by hydrogen whose atomic number is 1. In the second position comes helium and its atomic number is 2. In this way, the heaviest element uranium occupies 92th. position in the periodic table while its atomic number is 92.

Ordinarily, the letter Z represents the atomic number. So, we can say,

Z = the number of electrons outside the nucleus in an atom.

Since the number of protons in the nucleus equals the number of electrons outside the nucleus, it may also be said Z = the number of protons in the nucleus of an atom. From this, we can also say that

$A-Z$ = number of neutrons in the nucleus of an atom.

So, it is seen that if the mass number and the atomic number of an element are known, we can form an idea about the atomic structure of that element.

The notation usually adopted to designate a given atom is ${}_ZX^A$ where X stands for the chemical symbol of the element to which the atom belongs, A the mass number and Z the atomic number of the element. So, in an atom of that element, there are Z electrons outside the nucleus, Z protons and $(A-Z)$ neutrons in the nucleus. For example, ${}_{17}Cl^{35}$, ${}_{10}Ne^{20}$, ${}_{13}Al^{27}$, etc. In these Cl represents chlorine atom which has 17 electrons, 17 protons and $(35-17)=18$ neutrons. Likewise, Al stands for aluminium atom and it has 13 electrons, 13 protons and $(27-13)=14$ neutrons.

1·3. Fundamental particles :

Electron : Electron enters into the constitution of every element. It is the lightest particle known and its mass is $9·1 \times 10^{-28}$ gm ; we do not know any other particle lighter than an electron. It is about 1836 times lighter than the atom of the lightest element hydrogen. It carries negative charge whose amount is $4·8 \times 10^{-10}$ e.s.u. It is the smallest amount of charge known to us and hence it is taken as a unit of charge. It is exceedingly small in dimension, the diameter being $5·6 \times 10^{-13}$ cm

Proton : Proton enters into the constitution of the nuclei of all elements. Its mass is same as the mass of hydrogen atom and is about 1836 times heavier than an electron. Its mass is $1·67 \times 10^{-24}$ gm ; it carries positive charge, the amount being equal to that of an electron, *viz*, $4 8 \times 10^{-10}$ e.s u.

Neutron : Save and except hydrogen atom, other atomic nuclei contain neutron like proton. It is electrically neutral and its mass—$1·675 \times 10^{-24}$ gm.—is slightly greater than that of a proton.

Isotopes : It has been mentioned before that isotopes of a given element are such substances which have precisely the same physical and chemical properties as those of the element but different atomic weight. Scientists were aware of the existence of isotopes in the case of elements of higher atomic weight *i.e.*, radioactive substances such as uranium, actinium, thorium, etc. But after the discovery of positive rays in the last decade of nineteenth century, it became known that almost all elements—radioactive or non-radioactive—have got isotopes. Even the simplest element hydrogen has two isotopes, *viz.* deuterium and tritium [Fig.3].

Exercises

1, Why is electron considered as a fundamental particle in the constitution of matter ? Is there any other fundamental particle ? What are the mass and the charge of an electron ?

2. What are the similarities between the structure of an atom and that of the solar system ? Who pointed out the similarities first ?

3. What is a proton ? What is the relation between the masses of a proton and an electron ?

4. Which particles the nucleus of an atom is composed of ? Describe its structure.

5. What is an isotope ? What is its structure ? What are the isotopes of hydrogen ?

6 What is a neutron ? Is it a fundamental particle ? What is its mass ?

7. Explain the terms : Atomic weight, Mass number and Atomic number,

8 Write a short essay on the structure of an atom.

9. How can you express an atom by notation ? Explain it fully.

10. Notations of some atoms are given below. Find out the number oi electrons, protons and neutrons in each of them :

(a) ${}_{6}C^{12}$ (b) ${}_{88}Ra^{226}$ (c) ${}_{7}N^{14}$ (d) ${}_{8}O^{16}$.

11. Write the notations of the atoms from the following data :

(a) for phosphorus (P) atom, $Z=15$ and $A=31$

(b) ,, Berellium (Be) ,, $Z=4$ and $A=9$

(c) ,, Boron (B) ,, $Z=5$ and $A=10$

(d) ,, Magnesium (Mg) ,, $Z=12$ and $A=24$

(e) ,, Uranium (U) ,, $Z=92$ and $A=238$

12. Two atoms have their atomic numbers equal but have different atomic weights. This shows that they have

(i) equal number of protons and equal number of neutrons

(ii) equal number of protons but different number of neutrons

(iii) equal number of neutrons but different number of protons. Which one is correct ?

CHAPTER TWO

PROPERTIES OF GASES

2 1 Properties of gases :

Gases and liquids have several properties in common. For example, both have weight, volume, pressure, etc. Properties in which they seem to differ are, in reality, only different degrees of the same property ; such as in both of them, the molecules are capable of moving ; in gases quite freely but in liquids not so freely. It is due to this restricted mobility of the liquid molecules that a liquid maintains definite size or volume but assumes the shape of the container. In a gas, the molecules are rather free to move and as a result a gas has neither shape nor volume of its own It always occupies the volume of its container. 200 c.c. of water, when poured into a vessel of **400** c.c. capacity, will always occupy **200** c.c. but **200** c.c. of gas when similarly poured, will at once occupy the entire volume (*i.e.*, **400** c.c.) of the vessel.

Expansibility of gases :

One of the characteristics of a gas which distinguishes it from a liquid is its expansibility. The volume of a certain mass of a gas changes appreciably due to a slight change in its pressure and temperature. For this reason, whenever the volume of a gas is mentioned, its temperature and pressure are also mentioned. '**10** c.c. of hydrogen or oxygen' – statements like these are meaningless unless the temperature and pressure are mentioned because at a certain temperature and pressure, a definite quantity of hydrogen or oxygen may occupy **10** c.c. but with the change of temperature or pressure or both, the same quantity of the gas may occupy entirely different volume.

The expansibility of gases will be clearly borne out from the following simple experiments :—

(*a*) Fill a toy balloon with some air or gas and close its mouth tightly. Now, warm it slightly. The balloon will swell up. The air in the balloon, being heated, expands in volume and exerts outward pressure on the balloon, which, therefore, swells up. Now, cool the balloon to its original temperature. The volume of the balloon will also contract to its original dimension.

(*b*) Close the mouth of a glass bottle by a cork and place it by the side of an oven. You will here a loud report after sometime and will see that the cork has been thrown away to a certain distance from the bottle. Why does it happen so ? Due to the heat of the oven, the air in the bottle tries to expand in volume and exerts a great pressure on the cork as well as on the glass walls of the bottle. This increased pressure forces the cork out of the bottle.

(c) You must have seen that milk swells up when heated. Half pan-ful of milk, if heated, will swell and fill up the whole pan. What is the reason of it ? Some air always remains dissolved in milk. On being heated, this air expands in volume and causes the swelling of milk.

All gases expand equally due to equal amount of heat :

Gases, like solids and liquids, expand when heated but one of the characteristics of gases is that all gases expand equally due to equal amount to heat. This is not the case with solids and liquids. The following experiment demonstrates this characteristic of gases :

Experiment : Take some coloured water in a thin-walled glass flask and close its mouth with a cork [Fig. 1] Insert a thin glass tube through the hole in the cork so that the tube may reach the bottom of the flask. Besides water, there is air in the flask. Now, wrap the upper part of the flask by your palm and you will see that the coloured water rises to a certain height in the glass tube.

Due to the heat of the palm, the air in the flask tries to expand in volume and exerts a pressure on the water surface. This pressure forces water up along the tube. Now take two such flasks and fill them partly with equal quantities of coloured water so that each has the same volume left for holding gases. Suppose, one of them contains air and the other equal volume of hydrogen. Now place the flasks in a vessel containing warm water. It will be seen that coloured water has gone up the glass tubes to equal heights. This clearly shows that gases expand equally due to equal amount of heat.

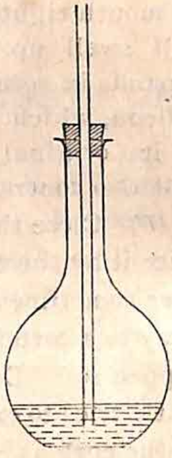


Fig. 1

Motion of gas molecules :

Any substance, be it solid, liquid or gas, contains numerous molecules. The molecules of a solid are densely packed and have strong binding forces between them. This is why a solid substance has a definite shape and volume. The liquid molecules are less densely packed and have less binding forces between them, for which a liquid has no definite shape but has a certain volume. The molecules of a gas, on the other hand, have very very weak binding forces between them and compared to the solid and liquid molecules, they are widely separated from each other. Consequently, gas molecules move more or less freely in the enclosure in which the gas is kept.

If we examine a certain amount of any gas by a microscope, we will see that gas molecules are moving chaotically in all directions with all possible speeds. Due to this random motion, the molecules constantly collide against one onother as well against the wall of the enclosure. On every collision against the wall, a molecule hands over some momentum to the wall. Since in the enclosure, there are thousands of gas molecules, a large number of collisions against the wall take place every moment and this exerts a pressure on the wall. This is referred to as the *gas pressure.* As jets of water directed against a wall by a hose-pipe, exert pressure on the wall, so also the gas molecules exert pressure on the walls of the enclosure.

It is clearly seen that if the volume of the enclosure containing the gas be diminished, then the pressure of the gas on the walls of the enclosure increases, for, the same number of gas molecules now occupy a smaller space and come closer to each other, thereby increasing the number of collisions against the walls. On the other hand, if the volume be increased, the pressure diminishes.

Experiment : Take a glass tube and introduce a tightly fitting piston *P* halfway in the tube [Fig. 2(i)]. Introduce some smoke through the other end of the tube to make visible the volume of air in it. Now close this end by a thin rubber sheet. When the piston is pushed towards the sheet, the volume of the air in the tube decreases. It will be seen that the rubber sheet bulges out [Fig 2(ii)]. What does it indicate ? It indicates that the pressure of

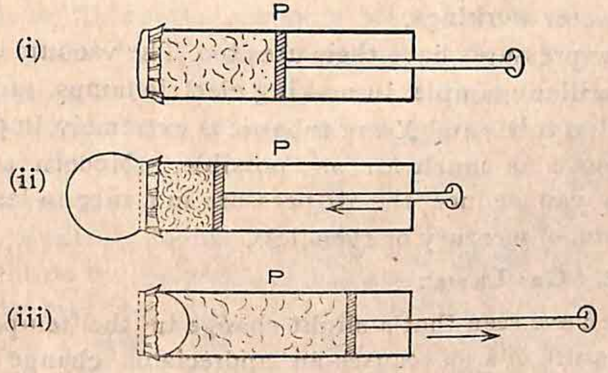


Fig. 2

air in the tube increases when its volume is diminished. Now, the piston *P* is moved backwards to its original position, so that the sheet flattens again. This shows that when the volume of air increases the pressure diminishes.

If the piston be pulled further backwards, the volume will diminish further and the pressure of air in the tube will be smaller than the pressure of air outside. At this time, the rubber sheet will be found to bulge inwards [Fig. 2(iii)].

It is needless to mention that when the sheet is flat, the pressures of outside air and the air inside the tube are the same and the sheet is pressed equally on both the sides. Same results will be obtained if air is replaced by any other gas. So, we can conclude that *if the volume of a gas be diminished, its pressure increases and vice versa.*

Again, if a gas be heated, its molecules move with greater speed and hand over greater momentum to the walls of the enclosure against which they collide. This evidently increases the gas pressure. The glass bottle experiment described in art. 2·1 illustrates this

Uses of air pressure :

There are many uses for compressed air : it is utilised in inflating tyres, in operating air brakes and tools such as the riveting hammer and in keeping water out of underwater workings.

Low pressures have their uses too. The vacuum cleaner is a familiar example. In making electric lamps, radio and television tubes and *X*-ray tubes it is extremely important to remove as much air as possible. Modern vacuum pumps can reduce the air pressure in a tube to less than ·001 mm. of mercury or even less.

2·2. Gas Laws :

We have seen that a slight change in the temperature or pressure of a gas causes an appreciable change in its volume. Change of volume of a solid or liquid due to slight changes in its pressure is so small that it can be easily ignored. But, the volume of a gas undergoes appreciable change due to a small change in its pressure, even when its temperature is unchanged. Similarly, the volume of gas changes appreciably due to a small change in its temperature, even when its pressure is unchanged. Pressure of a gas, on the other hand, changes due to a change in temperature, when the volume of the gas is kept unchanged. For this reason, the study of behaviour of a gas requires the consideration of its volume, pressure and temperature. Their relationships are guided by three laws known as *gas laws*.

(a) **Boyle's law :** *The volume of a certain mass of gas at constant temperature is inversely proportional to its pressure.*

If V be the volume of a certain mass of gas and P its pressure then according to Boyle's law,

$$V \propto \frac{1}{P} \text{ when the temperature remains constant.}$$

i.e., $V\,P = \text{constant}$.

So, if the volumes of a certain mass of gas be V_1, V_2, V_3 etc. and the corresponding pressures be P_1, P_2, P_3 etc. then,

$$V_1P_1 = V_2P_2 = V_3P_3 = \text{etc.}$$

As an illustration, suppose we take 100 c.c. of a gas in a vessel. The pressure exerted on the gas by a piston is equal to 1 atmospheric pressure and its temperature is 30°C. [Fig. 3(i)]. Now, the temperature of the gas is kept the same, but the pressure is doubled by putting double weight on the piston. According to the Boyle's law, the volume of the gas will be reduced to $\frac{100}{2} = 50$ c.c. [Fig. 3 ii)]. Now, the pressure on the gas is increased four times by putting load four times than the first. The volume of the gas will be reduced in

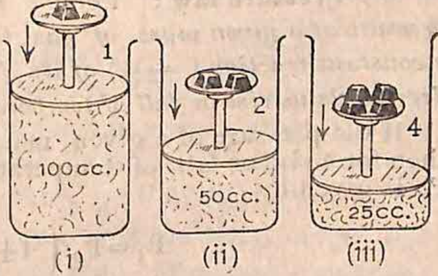


Fig. 3

the same proportion *i.e.* it will be $\frac{100}{4}=25$ c.c. [Fig 3 iii)]. Now, if the pressure be halved *i.e.*, made equal to 2 atmosphere, keeping the temperature constant the volume will at once increase twofold and will be equal to $25\times2=50$c.c In the same way, a fourfold reduction in pressure (i.e., 1 atmosphere), will increase the volume of the gas fourfold and the volume will be $25\times4=100$ c.c.

(b) **Charles' law :** *Pressure remaining constant, the volume of a given mass of a gas increases or decreases by a constant fraction* $(=\frac{1}{273})$ *of its volume at 0°C* for *each degree celsius rise or fall of temperature.*

If V_0 represents the volume of a given mass of gas at 0°C, then from the law, we have

$$\text{Volume at } 1°C=V_0+V_0.\tfrac{1}{273}$$
$$\text{,, ,, } 2°C=V_0+V_0.\tfrac{2}{273}$$
$$\text{,, ,, } t°C=V_0+V_0\ \frac{t}{273}$$

If V_t represents this volume at t°C, then,

$$V_t=V_0+V_0\frac{t}{273}=V_0\left(1+\frac{t}{273}\right)$$

Similarly, when the temperature of the same mass of gass be gradually made to decrease, its volume at $-t$°C is given by,

$$V_t=V_0-V_0.\frac{t}{273}=V_0\left(1-\frac{t}{273}\right)$$

(c) **Pressure law :** *Volume remaining constant, the pressure of a given mass of gas increases or decreases by a constant fraction* $(=\frac{1}{273})$ *of its pressure at 0°C for each degree celsius rise or fall of temperature.*

If the pressure of a given mass of gas at 0°C be P_0; then for a rise or fall of tempetature of t°C, its pressure P_t is given by

$$P_t=P_0\left(1\pm\frac{t}{273}\right)$$

Absolute Scale and Absolute Zero :

From Charles' law we see that under constant pressure the fractional change in volume of a gas due to temperature change is always constant, regardless of the kind of gas used. Starting from 0°C, the change amounts to $\frac{1}{273}$ of the original volume for each celsius (formerly centigrade) degree change in temperature. This means that for every degree that the temperature is lowered, the volume decreases by $\frac{1}{273}$ of its value at 0°C and suggests that if the temperature were lowered 273° below the ice point (0°C) the gas would no longer occupy any space !

Similarly, from the pressure law it follows that if the temperature be lowered 273° below the ice point, the gas would no longer exert any pressure at all—provided, of course, the gas does not first liquefy or solidify

Both these conclusions point to the existence of a lowest possible temperature of −273°C, where a gas would no longer take up any space or exert pressure on its container. This temperature is called the *absolute zero.* In the laboratory, Physicists have been able to reach within a few thousands of a degree of this point.

For all theoretical purposes, scientists measure temperatures upward from the absolute zero as a starting point, using the celsius degree as the unit. This scheme is called the *absolute* or *Kelvin scale.* To change from a celsius reading to Kelvin, simply add 273. For example, a summer temperature of 40°C is equivalent to 40+273 =313°K.

2·3. Avogadro's hypothesis :

The concept of atoms was first introduced by John Dalton to explain the formation compounds from simpler substances called elements. He told that substances are composed of tiny particle which are indivisibie and called them 'atoms'. He further said that the atoms of any one element were identical in all their properties including weight but atoms of different elements differ from one another in properties as well as in weight. This is known as Dalton's atomic theory.

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Many of the elements and compounds are available in gaseous state. It was found that the volumes of the elements and compounds involved in a chemical reaction, in which both the initial and final constituents were gases, were connected by very simple relationship. This was first noticed by a French chemist named Gay Lussac. He found experimentally that hydrogen and oxygen react chemically in gaseous state to form water vapour which is also a gas. He further found that at the same tempeture and pressure, *two volumes* of hydrogen and *one volume* of oxygen combine to form *two volumes* of water vapour. Gay-Lussac was surprised to find the simple ratio (2 : 1 : 2) existing between the volumes of hydrogen, oxygen and water vapour. He asked himself, "Do all other gases combine in such simple ratios to form new gaseous compounds?" He. then, prepared hydrochloric acid gas by combining hydrogen and chlorine gas. In this case also he found the same simple ratio to exist between the volumes of the reacting gases and the product gas. In this way, experimenting with many other gases he found the same rule to exist from which he formulated a law known, after his name, as *Gay-Lussac's law.* The law states that when different gases react with each other chemically to produce gaseous substances, then under the same condition of temperature and pressure, the volumes of the reacting gases and the product gases bear a simple ratio among one another. In trying to explain the above law by Dalton's atomic theory Berzilus came to a very important conclusion. The conclusion is that under the same condition of temperature and pressure equal volumes of all gases contain equal number of atoms. This is known as *Berzilus' hypothesis.* But a serious difficulty arose in the application of the hypothesis in the chemical reactions of the gases. It was found that for a satisfactory explanation of chemical behaviour of gases, atoms have got to be subdivided which is forbidden according to Dalton's atomic theory. To surmount this difficulty Avogadro took a bold step. He visualised two kinds of ultimate particles of matter and called them *molecules* and *atoms*. The following properties were attributed to the molecules and the atoms:

(*i*) Molecules retain the properties of the elements or of the compounds to which they belong and have free existence. For example, molecules of water, hydrochloric acid gas, etc.

(*ii*) Atoms do not exist in free state but take part in chemical reaction.

(*iii*) Molecules are divisible but atoms are not. Two or more atoms combining together make a molecule. For example, by splitting one water molecule, we get two hydrogen atoms and one oxygen atom. The hydrogen atom or the oxygen atom cannot be further split up Similary, if we split one hydrochloric acid gas molecule, we get one hydrogen and one chlorine atom.

With this idea of atoms and molecules, Avogadro modified Berzilus' hypothesis in the following line : *Under the same condition of temperature and pressure, equal volumes of all gases contain equal number of molecules.* This is known as Avogadro's hypothesis. This hypothesis, therefore, means that at a certain temperature and pressure, if a vessel be filled up with various gases-element or compound —then in each case, the number of gas molecules in the vessel will be equal. For example, 1 c.c. of oxygen or 1 c.c. of hydrogen will contain as many molecules as 1 c.c. of chlorine or 1 c c of nitrogen or any other elementary or compound gas contains under the same condition of temperature and pressure. If 1 c.c. of hydrogen contains 5000 millions of molecules at a certain temperature and pressure then 1 c.c. of any other gas, at the same temperature and pressure, will contain the same number *i.e.*, 5000 millions of molecules.

Applications of Avogadro's hypothesis :

Solving many knotty problems satisfactorily, Avogadro's hypothesis has caused a great advancement to the science of chemistry. By its application, it may be proved that :

(i) The molecules of elements like hydrogen, oxygen etc. are di-atomic.

(ii) The molecular weight of a gaseous substance is twice its vapour density.

(iii) At normal temperature and pressure, the gram-molecular volume of all gases is equal and it is equal to 22 4 litres.

(iv) The molecular formula of a gaseous substance can be determined.

2·4. Molecular weight and Avogadro number :

The molecules of an element or a compound are so small that direct determination of their weight is not possible. Like atomic weight, molecular weight of a substance is also measured in comparison with a standard substance, *viz*, oxygen atom whose weight is taken as 16. It may be defined as the number of times a molecule of a substance is heavier than one-sixteenth of the weight of an atom of oxygen So,

$$\text{the molecular weight} = \frac{\text{Wt. of a molecule of the substance}}{\frac{1}{16}\text{ of the wt. of an atom of } O_2}$$

In order to calculate the molecular weight of an element or a compound, at first, the number of constituent atoms are to be ascertained from its molecular formula because, *the molecular weight of an element or a compound is the sum-total of the atomic weights of the atoms which constitute a molecule of the substance.* For example, the molecular weight of water is 18·016. This is because $H_2O = H + H + O = 1{\cdot}008 + 1{\cdot}008 + 16 = 18{\cdot}016$. The molecular formula of nitric acid is HNO_3 ; hence its molecular weight $= H + N + 3 \times O = 1 + 14 + 3 \times 16 = 63$ (taking atomic wt. of hydrogen as 1). It is to be always borne in mind that the atomic weights do not represent the actual weights of the atoms ; the atomic weight of O_2 is 16, that of H_2 is 1·008, that of C is 12—these figures do not indicate the actual weight of an atom of H_2 or of O_2, etc. Similary the molecular weight of oxygen is 32, that of hydrogen 2·016, that of water 18·016—these figures also do not indicate the actual weight of a molecule of oxygen or of hydrogen, etc. These figures indicate numerical comparison with respect to a standard.

A quantity of any substance whose mass, in grams, is numerically equal to its molecular weight, is called *gram-molecular weight* or *mole*. For example, molecular weight of oxygen is 32; hence the gram-molecular weight of oxygen will be 32 grams; molecular weight of water-vapour is 18·016 and the gram molecular weight of water-vapour will be 18·016 grams.

The volume occupied by a mole of any gas is called the *gram-molecular volume.* On the basis of Avogadro's hypothesis, the gram-molecular volume of any gas at normal temperature and pressure is 22·4 litres and every mole of a substance contains the same number of molecules. This number is known as *Avogadro number* and is equal to $6·06 \times 10^{23}$; for example, there are $6·06 \times 10^{23}$ molecules present in 32 gms. of oxygen or 44 grams of carbon di-oxide because 32 gms. and 44 gms. are the gram-molecular weights of oxygen and carbon di-oxide respectively.

Exercises

1. Mention some common occurrences which illustrate that gases are more expansible than solids or liquids.
2. What are the characteristics of a gas?
3. Why does the pressure of a certain quantity of gas change due to the change of its volume and temperature?
4. Mention the gas laws and explain them clearly.
5. What is Avogadro's hypothesis? How did Avogadro arrive at this hypothesis?
6. Explain clearly what you understand by molecular weight and Avogadro number? What is the magnitude of Avogadro number? Is it a constant quantity?
7. State Gay-Lussac's law relating to the volume of a gas.

8. What is the distinction between an atom and a molecule ?
9. What are absolute scale of temperature and absolute zero ?
10. What is the relation between absolute scale and celsius scale ?
11. The temperature on a day is 27°C. What is it on the absolute scale ?
[Ans. 300°k]

12. Certain statements are made below. Make necessary corrections wherever you find fault in the statements :

(i) One of the characteristics of a gas in comparison with liquids is that volume of a gas does not undergo any change due to changes in the pressure and temperature.

(ii) Equal amount of heat causes equal volume expansion, like solids, in all gases.

(iii) Gases can exert pressure due to the mobility of its molecules.

(iv) Temperature remaining constant, the volume of a certain mass of a gas increases due to the increase of its pressure and vice-versa.

(v) Pressure remaining constant, the volume of certain mass of gas increases or decreases by a certain fraction of its volume due to 1°C rise or fall of its temperature.

(vi) Under the same condition of temperature and pressure, equal volumes of all gases contain equal number of atoms.

PHYSICS

CHAPTER ONE

SOUND

1·1. Introduction :

Everyone of us has some idea as to what 'sound' is. We hear various sounds everyday. Sound of moving vehicles, sound of people talking to each other, sound of water falling from the tap and thousands of other sounds reach our ears daily. From our everyday experience of such sound, we are acquainted with some preliminaries of it. For example, we know that some sounds are sweet to hear and some are harsh. Sound of musical instruments, of rivulets, etc. are pleasing but sounds of moving carriages, machines, etc. are not so. In discussing sound in this chapter, we shall come to know some other important facts about it.

It is to be always remembered that like heat, light, etc. *sound is also a form of energy*. Like all other energies, sound is not visible to us. It produces a sensation of hearing when it reaches our ears.

1·2. Sound is produced by vibration :

Every sound is found to originate from a vibrating body. If you strike a brass bell you will hear a sound and if you touch the bell you will feel that it is vibrating. If a brass vessel falls on the floor, it produces a loud sound and if the vessel is touched it will be found to be vibrating. *Sound cannot be produced without vibration.*

Thus, sound is a peculiar sensation produced in the ear by vibration of bodies when the energy of vibration is transmitted to the ear through a certain material medium.

The following simple experiments may be done in a laboratory to demonstrate that vibrations are necessary for the production of sound.

Experiments :

(1) *With the help of a tuning fork* : A tuning fork (Fig. 1) has two hard steel prongs bent in the form of U with a handle attached to it. It is mounted on a hollow wooden box. When any of the prongs is struck gently with a padded hammer, the prongs vibrate and a sound is produced. If a suspended pith-ball be brought in contact with one of the prongs of the fork, the ball will be kicked away repeatedly as in Fig. 1. This demonstrates that the prongs of the fork vibrate while the fork produces a sound. If the prongs be now touched with the finger, the fork will stop vibrating and the sound will also be stopped.

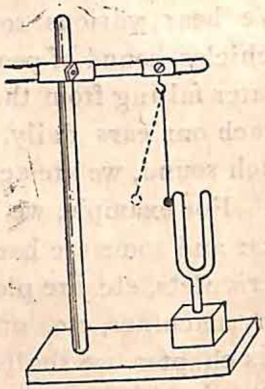


Fig. 1

(2) Stretch a metallic string tightly between two points and pluck it at its centre. A sound will be produced and at the same time, the string will vibrate rapidly as evidenced by its hazy appearance (Fig. 2). If a small paper rider be placed on the string, the rider will be thrown away. This shows that the string, owing to its state of vibration, is producing sound.

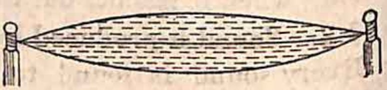


Fig. 2

1·3. Necessity of a material medium for propagation of sound :

For propagation of sound, a material medium (solid, liquid or gas) is necessary. Sound cannot travel through a vacuum. If there be no material madium, sound will not reach our ear and we will not hear any sound.

Experiment : An electric bell is suspended in a bell-jar which is placed on the receiver of an exhaust pump

[Fig. 3]. When the bell-jar is full of air and the electric bell worked, the sound can easily be heard. Now, with the bell ringing, if the air is gradually pumped out, the sound becomes fainter and fainter until it is inaudible although the hammer can still be seen striking the gong.

If the air be readmitted, the sound becomes louder once more.

This experiment, therefore, shows that a material medium (air in the above experiment) is necessary for the propagation of sound.

Sound can also travel through solids and liquids. If the ear is applied to one end of a long table while someone lightly scratches the other end, the sound of the scratching will be plainly heard though it may be inaudible when the ear is removed from contact with the table. The sound of an approaching train is audible at a long distance away if the ear is brought in contact with the line The toy-telephone prepared by children by fastening two match boxes at the ends of a long cord is also an example of propagation of sound through solids.

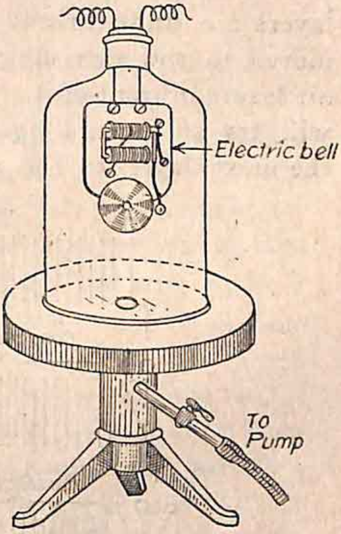


Fig. 3

The sound of clapping under water can be picked up at some distance away by another man dipping in water, while the sound may not be audible from outside.

When rain-drops fall on a sheet of water, the sound is not heard from outside. But if a man dips in the water, he will clearly hear the clattering sound of rain-drops. In this case, sound is transmitted through water.

About three hundred years ago Von Guericke, the Prussian scientist, found that fish were attracted by the sound of a bell rung under water and therefore, concluded that sound could travel through water as well as through air. In recent times, fishermen are using transistor "Beepers" which when lowered into water, are found to attract fish by producing sound.

1·4. Propagation of sound :

Let us now enquire as to how sound is propagated through a medium.

Suppose sound is coming from a vibrating tuning fork. The layers of air in front of a prong are shown in Fig. 4(i), when the prong is not vibrating. In this case, the layers are undisturbed. When the prong vibrates and moves to the extreme right position *b*, it compresses the air layers in front of it. Owing to its elasticity this layer will try to expand again and in so doing will compress the next layer to the right and so on. The distance between the layers, thus, decreases. This state is called *condensation* or, *compression* [Fig. 4(ii)]. When the prong moves to the left it will relieve the pressure on the layer immediately to its right and the layers become rarefied. This state is called *rarefaction* [Fig. 4 (iii)]. In this way

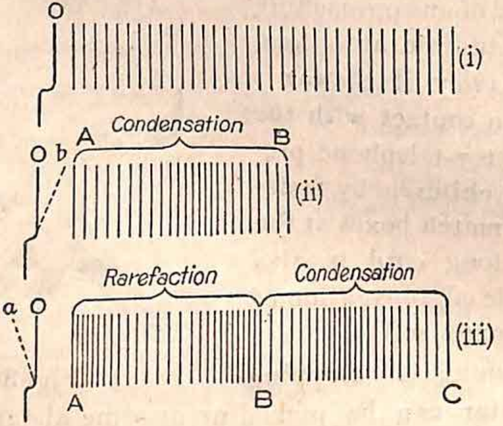


Fig. 4

compressions and rarefactions are formed as long as the fork vibrates and they travel in all directions in the air keeping their relative positions unchanged. When they

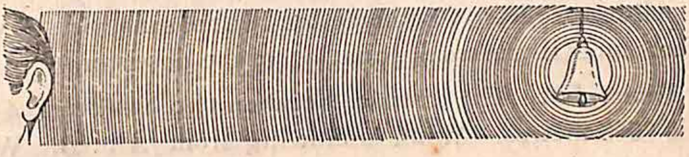


Fig. 5

reach our ears, we hear sound. How sound waves produced by a bell travel in all directions are shown in Fig. 5.

1·5. Velocity of sound :

You must have noticed that a thunder clap is usually heard a few seconds after the lightning flash is seen. As a matter of fact, both happen simultaneously. It shows that sound takes some time to travel from the cloud to the earth, while light does not, because light has the tremendous speed of 1,86,000 miles per second and covers up the distance in a twinkling of an eye. Consequently, flash is seen as soon as it is produced but the sound takes some time to reach the observer. In watching a cricket match from a distance, the sound of the bat hitting the ball is not heard until a short time after the batsman has been seen to make his stroke. When a distant train whistles, sound is heard some time after the smoke is seen. From these illustrations, we may say that sound requires some time to cover up a distance *i.e., the sound has a definite velocity*. Experiment shows that the velocity of sound in air at 0°C is about 332 metres per second or 1120 ft/sec

Some French scientists carried out an experiment to determine the speed of sound in open air in 1822. They engaged two observers in two hills about 18 miles apart. One fired a gun and the other timed the interval between seeing the flash and hearing the sound with the help of a stop-watch. If the time-interval be 't' and the distance between the observers S, then, the velocity of sound $V=\frac{S}{t}$.

Allowance has to be made for two reasons, *viz.*, (i) wind effects and (ii) personal equation of the observer.

Example : The distance between two observers A and B is 7968 metres. Wind is blowing from A to B. When A made a sound, B heard it 20 seconds later. When B made a sound, A heard it 30 seconds later. Calculate the velocity of sound.

Ans. Suppose, the velocity of sound $=V$ metre/sec. and the velocity of wind $=v$ metre/sec. If wind blows from A to B, the effective velocity of sound in that direction $=(V+v)$ metre/sec. If sound takes 20 seconds to travel from A to B, then,

$$(V+v)\times 20=7968 \ldots\ldots \text{(i)}$$

Again, the effective velocity of sound in the direction from B to $A=(V-v)$ metre/sec. If sound takes 30 seconds to travel the same distance in that direction, then,

$$(V-v)\times 30=7968 \ldots\ldots \text{(ii)}$$

From the equations (i) and (ii), we have,

$$V+v=\frac{7968}{20}$$

$$\text{and} \quad V-v=\frac{7968}{30}$$

$$\text{Adding,} \quad 2V=7968\left(\tfrac{1}{20}+\tfrac{1}{30}\right)=\frac{7968\times 5}{60}$$

$$\therefore \quad V=\frac{7968\times 5}{2\times 60}=332 \text{ metres/sec.}$$

1·6. Effect of density, pressure, temperature and humidity of a gas on the velocity of sound through it :

(i) **Effect of density :** The velocity of sound through a gas is inversely proportional to the square root of the density of the gas. Thus, the density of oxygen is 16 times that of hydrogen ; hence the velocity of sound through oxygen is $\frac{1}{4}$ the velocity of sound through hydrogen.

(ii) **Effect of pressure :** It may be proved that change of pressure of a gas does, in no way, affect the velocity of sound in it. For example, if the velocity of sound in air at 0°C and 76 cm. of mercury pressure be 332 metres/sec. then, the velocity of sound will remain same whatever be the pressure provided the temperature remains at 0°C.

(iii) **Effect of temperature :** It has been seen that the velocity of sound in a gas increases if the temperature of the gas is increased. If V_0 be the velocity of sound in a gas at 0°C, then at t°C, the velocity of sound will be $V_t = V_0\ (1 + {\cdot}00183 \times t)$; we know at 0°C, the velocity of sound in air $V_0 = 332$ metres/sec. Hence, at t°C, the velocity of sound in air is

$$V_t = 332(1 + {\cdot}00183 \times t) = (332 + 0{\cdot}61t) \text{ metres/sec.}$$

It may, therefore, be said that for each degree centigrade rise in temperature, the velocity of sound in air increases at the rate of 61 cm./per sec.

(iv) **Effect of humidity :** The velocity of sound in a gas increases with the increase of humidity of the gas.

1·7. Reflection of sound :

You have seen reflection of light by a mirror. In this respect, sound also behaves in the same manner *i.e.*, by suitable reflectors, sound can be reflected like light. Reflectors, in the case of light, should be very smooth. But for sound, the reflectors may be rough. That is why brick wall of a building, rows of trees, mountains, etc. may act as sound reflectors.

Experiment : Two metal or cardboard tubes A and B are set up, inclined to each other in a horizontal plane and pointing towards a vertical flat surface C of any hard material, e.g., a wooden board [Fig. 6]. A ticking watch is placed near the end of the tube A and the ear is placed to the end of the tube B. Sound waves pass down the tube A, get reflected by the board C and enter into the tube B. The loudness of the sound heard through the tube B is maximum when the tube B is so adjusted that the axes of the two tubes make equal angles with the normal CP i.e., ∠PCA = ∠PCB. It shows that sound rays are reflected in the same manner as the light rays and they obey the same laws of reflection. The wooden partition P placed between the two tubes prevents sound from reaching the ear directly.

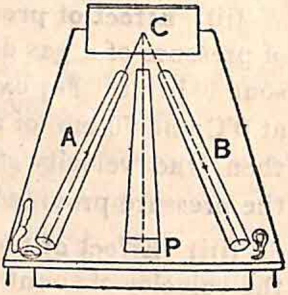


Fig. 6

1·8. Practical application of reflection of sound :

(i) Before the advent of microphones and loudspeakers, parabolic reflectors were used in large lecture-halls. The speaker used to stand at the focus of the reflector and the sound rays reflected by the reflector were thrown forward and could reach the farthest end of the hall without sensible diminution in intensity.

(ii) For communication of speech between the driver and the passenger, large automobiles are provided with

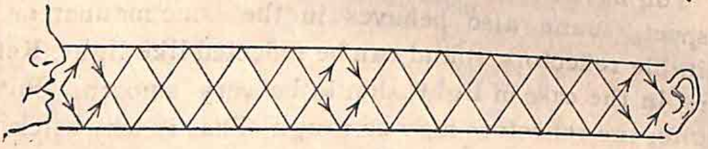


Fig. 7

long tube, called 'speaking tube' [Fig. 7]. If a sound is made at one end of the tube, the sound-waves will travel down the tube by the process of multiple reflections and will reach the ear at the other end of the tube.

(iii) Doctor's stethoscope is nothing but a speaking tube of the above nature. It consists of a conical face with a diaphragm at one end of the tube and a bifurcation at the other end. When the conical face (now-a-days, it is made flat) is pressed against the chest of a man, the throbbing of heart sets the diaphragm into vibration and the sound is carried along the tube to the ear.

The gramophone horn, the ear-trumpet used by deaf persons, etc. utilise the reflection of sound in their operation.

1·9. Echoes : *An echo is the repetition of sound caused by reflection from some distant obstacle.* Thus when a sound is produced near a hill or a row of building, an echo is generally heard.

A clear echo cannot be heard unless the reflecting surface is at more than a certain minimum distance from the place where the original sound is made. This is due to the fact that the effect of a sound persists in the ear for some time and if the echo reaches the ear in that period it merely seems to prolong the sound and is not heard separately. The sensation due to a short sound persists for about $\frac{1}{10}$ second and is known as *presistence of hearing*. In that time sound can travel 112 ft., if the velocity of sound is taken as 1120 ft/sec. That is, the sound could go to a surface 56 ft. away and return in time. Thus clear echoes will not be heard unless the reflecting surface is at a distance more than 56 ft. from the source of sound. That is why, we do not hear echoes when a sound is made in a room of ordinary size.

If a sound is made between two reflecting surfaces, the sound waves may be reflected from one to the other a number of times causing an echo each time they pass the listener.

This is frequently observed in wide valleys with almost parallel cliffs on each side. Near Verdun in France there are two parallel towers at a distance of about 164 ft. Any sound made between the towers will have at least 12 echoes produced in succession. Rumbling of cloud is produced due to multiple reflections of sound by clouds at different levels.

If the reflecting surfaces are near enough to each other, the echoes will not be heard as separate sounds, but owing to persistence of hearing they will seem to be continuous with original sound and give the impression of a long drawn out sound having been made. This is referred to as *reverberation*. Reverberation is particularly noticeable in large halls and churches where multiple reflections of sound occur from walls, roof and floor. Tapestry, wall cushions and curtains in a room help to deaden the reverberation by absorbing sound waves.

1·10. Echo depth-sounding :

The depth of a sea can be found by employing sound echoes. For this purpose a submerged hydrophone—an instrument for recording sound wave in water—is placed near a small underwater charge of explosives. When the charge is fired, the direct sound of the explosion is heard through the hydrophone and a little later the echo of it from the sea-bed is heard, the interval between the two sounds being electrically recorded. If the time-interval be t and the velocity of sound in sea-water V, then the total distance travelled by the sound-wave in that time is $V.t$. Hence, the depth of the sea 'd' is given by,

$$d=\frac{Vt}{2}.$$

Another device based on the same principle is the *Asdic*, which was used in time of war for locating enemy submarines. It consists of a sound transmitter attached to the bottom of a warship. It is kept rotating continuously so that the sea is swept over a complete circle. Any submarine or even a mine which happens to be within the range of sound waves will reflect the waves back to the ship. Here, the recording apparatus automatically gives the range and position of the submerged object.

It is important to note that the sound impulses sent out by *Asdic* have a frequency of the order of 50,000 cycles per sec. High frequency waves of this type are said to be ultrasonic (see Art. 1·11), as they are not audible to human ear. In this connection they have a twofold advantage. First, they cannot be confused with engine noises or other sounds made by the ship. Secondly, very high-frequency waves can be confined to a very narrow beam and hence can penetrate sea-water to large distances without appreciable loss of energy.

Examples : (1) A boat approaches a high vertical cliff. When the anchor is dropped, an echo is heard 2 sec. later. How far is the boat from the cliff ? (Velocity of sound = 332 metres/sec.)

Ans. Total distance travelled by sound in 2 sec $= 2 \times 332 = 664$ metres. For an echo, the sound must go to the cliff and return through the same distance. Therefore, the distance of the cliff $= \frac{664}{2} = 332$ metres.

(2) In measuring the depth of an ocean, it was found that the sound of an explosion and its echo by the bed had a time-interval of 10 sec. between them. What is the depth of the ocean ? (Velocity of sound in water = 4716 ft/sec.).

Ans. Total distance travelled by sound in 10 sec.

$$= 10 \times 4716 \text{ ft.}$$

$$\therefore \text{ the depth of the ocean} = \frac{10 \times 4716}{2} \text{ ft.} = \frac{10 \times 4716}{2 \times 3 \times 1760} \text{ mile}$$

$$= 4\tfrac{1}{2} \text{ miles (nearly)}$$

1·11. Musical sound and noise :

We hear various sounds every day, of which some appear to be pleasing while others are not. In that respect, musical sounds may be said to be those which produce pleasing sensation in our ear and noise to be those which produce unpleasant or harsh sensation. It has been found that *musical sounds are caused by bodies undergoing regular vibrations*, such as musical instruments. On the other hand, noise is caused by irregular disturbances such as explosions, scratching, etc.

Musical sound has three important characteristics, *viz.*, (*i*) *loudness*, (*ii*) *pitch and* (*iii*) *quality*.

Loudness : Suspend a pith ball by a thread from a stand near the end of a prong of a tuning fork as shown in Fig. 1. Now set the fork into vibration by striking it gently with a padded hammer. Listen the sound and note the maximum distance to which the pith-ball is kicked away when it is made to touch the prong. Now stop the vibrations of the fork by touching it with finger. Again strike the fork harder. Note the sound emitted and the maximum displacement of the pith-ball.

You would see that the sound in the second case was louder than in the first and the displacement of the pith-ball was also larger in the second case. From this we may conclude that the *loudness of sound depends upon the magnitude of displacement* referred to above, which is known as the *amplitude* of vibration. It is proportional to the square of the amplitude.

The loudness of sound also depends upon the following factors :

(*i*) *Size of the sounding body* : If the size of the sounding body be bigger, it will set larger quantity of air surrounding it into vibration and this will increase the loudness of the sound.

(*ii*) *Relative position of the sounding body and the recipient* : The intensity of the musical sound is found to vary inversely as the square of the distance between the source and the recipient.

(*iii*) *Density of the medium* : The more is the density of the medium surrounding the sounding body, greater will be the intensity of the sound produced.

(*iv*) *Direction of the wind* : The intensity of sound is modified by the direction of the wind.

(*v*) *Neighbourhood of a resonant body* : A tuning fork made to vibrate in air cannot produce an audible sound but when it is vibrating in contact with a sound-box, the sound produced is louder.

Pitch : Pitch is the position of a note in the musical scale and *it depends upon the frequency of vibration of the source.* We speak of notes of high pitch whose frequencies are large and of low pitch whose frequencies are low.

Fig. 8 shows a metallic toothed wheel capable of rotating in a horizontal plane. A hard card is held lightly against the teeth of the wheel. If the wheel be now rotated at a uniform rate, a sound will be produced. Note the pitch of the sound. Now rotate the wheel at a greater speed. Note that a sound of higher pitch is produced. When the wheel rotates at a greater speed, the card is struck more frequently and the frequency of the sound increases, thereby raising the pitch of the sound. We, therefore, conclude that pitch of a sound is proportional to the frequency of the sound.

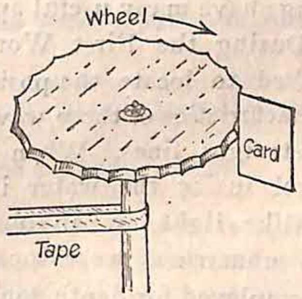


Fig. 8

Human ear responds to sound frequencies between 20 and 20,000 vibrations/sec. When you move your hand back and forth, no sound is heard because the vibrations are not fast enough to produce sensation of sound. The sound of human voice lies between the range of 60 and 13,000 vibrations/sec.

Quality : If a particular note on the musical scale is played on, say, a piano and a sitar, it is easy to distinguish the tone of one instrument from that of the other although their intensities are equal. The two tones are said to differ in *quality.*

Generally speaking, musical instruments do not produce tones which are pure in the sense that they consist of single frequencies only. In the majority of cases they consist of several different frequencies blended together. The strongest audible frequency present in the tone is called the **fundamental** and gives the note its characteristic pitch. The other frequencies are called **overtones** and these determine the quality of the sound. Quality is richer if the number of overtones present is higher.

1·11. Ultrasonic waves and their applications :

It has been mentioned before that the frequencies of audible sound range between 20 and 20,000 vibrations/sec. Those sounds whose frequencies are lower then 20 vib./sec. are called **subsonic sound waves** and those having frequencies higher then 20,000 vib./sec. are, called **ultrasonic waves.** Ultrasonic waves, though inaudible to human beings have many useful applications.

During the First World War, ultrasonic waves were applied to locate the position of submarines. One of the characteristics of these waves is that like light, they travel in straight lines. When directed in water, these waves travel inside the water in straight line and are bounced off, like light, by an obstacle in its path. In this way, the submarines were located. Now-a-days, these waves are employed for depth soundings.

Ultrasonic waves are now being used by fishermen. It has been found that fish air-bladder can reflect ultrasonic waves and by the reflected waves the depth and the direction in which shoals of fishes are moving can be ascertained.

Ultrasonic waves have dangerous effects on bacteria. For this reason, these waves are employed for sterilization of drinking water, milk and other food stuffs.

Medical science has utilised ultrasonic waves in various ways. Some substances which are ordinarily insoluble in water, can be made soluble by ultrasonic waves For example, camphor is insoluble in water, and as such it cannot be injected into human bodies directly. As an emulsion, it may be injected but that is dangerous to human life. For this reason, they are made soluble by ultrasonic waves and then injected into human bodies. Besides, the ultrasonic waves have been found useful in the preparation of a number of medicines.

Recently, it has been found that dirty linens can be easily cleaned by ultrasonic waves. In this way, ultrasonic waves are now-a-days being applied in industry, pure science, medical science and in various works of our daily life.

Exercises

1. 'Sound is produced by a vibrating body'—explain with suitable illustrations.

2. Can sound travel through a vacuum ? How can you give experimental evidence in support of your answer ? Will the sound of an explosion on the earth be audible in the moon ?

3. Explain how sound is propagated through a gaseous medium ?

4. Answer the following questions :

(a) The sound of an approaching horseman can be heard at a long distance away if the ear be kept in contact with the ground but no sound is heard if the ear be kept above the ground. Why ?

(b) If there be any leakage in the underground water-pipe how can it be detected from above the ground ?

(c) If one end of a long, hollow iron pipe be struck with a hammer, two sounds are heard at the other end. Why ?

(d) Why does an interval occur between the flash and the sound of a thunderclap ?

(e) Why does a rumbling sound occur after a loud report of the cloud ?

5. How would you determine the velocity of sound in open air ? Will it remain same in summer and in winter ?

6. State how the velocity of sound in a gas is affected by density, pressure, temperature and humidity of the gas ?

7. The sound of a cannon fire is heard 6 seconds after the flash was seen. How far was the listener from the cannon ? Velocity of sound = 1120 ft./sec.

[Ans. 6720 ft.]

8. Two observers *A* and *B* are standing in open air 1 mile apart. When *A* fires a gun, *B* sees the flash and 5 seconds later hear the report of the gun, Calculate the velocity of sound in air. [Ans. 1056 ft./sec.]

9. Describe an experiment to show that sound, like light, can be reflected.

10. What is an echo? What is the minimum distance of the reflector to produce an echo? How is depth-sounding made with the help of an echo?

11. Standing in front of a cliff, a person heard the echo of a sound 2 seconds later than the original sound. How far was the person from the cliff? Velocity of sound in air = 320 metres/sec. [Ans. 320 metres]

12. Describe some applications of multiple reflections of sound.

13. What is the difference between a musical sound and a noise?

14. A very high pitch note is heard when the teeth of a saw meet a log of wood but the pitch falls as the saw cuts into the wood. Why?

15. What is the range of audibility? What are the sounds of frequencies higher than the highest range of audibility called? What are their practical applications?

16. A few questions are set below. Put *N* against those whose answers are 'no' and *Y* against those whose answers are "yes".

(i) Can sound travel without material medium? —

(ii) Should a reflector of sound be very smooth? —

(iii) Can sound travel through solids and liquids? —

(iv) Can the reflector be placed at any distant from the source to produce an echo? —

(v) Is the pitch of sound proportional to its frequency? —

(vi) Is the velocity of sound equal in day and night? —

(vii) Will the velocity of sound be equal in all gases? —

(viii) Can we hear sound of all frequencies? —

CHAPTER TWO

ELECTRIC CURRENT

2·1. Sources of electric current :

The age we live in to-day may be called the age of electricity. In our everyday life, we take the help of electricity at various stages. Contributing much towards the industrial development of the country as well as human comforts, electricity is, now, intimately connected with our life. As a matter of fact, the industrial progress of a country is, to-day, gauged by the amount of electric power it consumes.

There are two ways for producing a steady electric current : (i) by *electric cells* and (ii) by *a dynamo.*

Electric cells are used to supply current in a small scale. For this reason, they are widely used for various works in laboratories. But for large scale supply such as power supply in towns, factories, etc. dynamos or generators are convenient.

2·2. Current and current strength :

A steady current flows through a conducting wire when it is connected to an electric cell. This flow of electric current is, in many ways, similar to the flow of water through a pipe. If a pressure difference at the ends of the pipe be maintained constant, the flow of water becomes steady (Fig. 1) and the amount of water flowing past any section of the pipe in 1 second measures the strength of water-current. If, for example, 50 gms. of water flow past any section of the pipe in 10 seconds, the strength of water-current $=\frac{50}{10}=5$ gms./sec. In the same way, when electricity flows through a wire in a steady rate, the amount of electricity flowing past any section of the wire

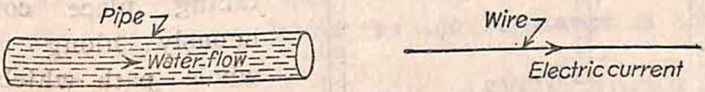


Fig. 1

in 1 second, measures the current strength in the wire. If Q amount of electricity flows across any section in t secs, then current strength $I=\frac{Q}{t}$.

2·3. Electromotive force of a cell:

Before taking up what electromotive force is, we shall discuss a little more about the similarity of electric current in a wire and the water-current in a pipe, because it will help us to understand the subject fully.

Suppose there is a tank at a height of about 10 ft. from a water-reservoir and they are connected together by several pipes, one after another (Fig. 2.) With the help of a tap in the pipe, flow of water in the pipe may be started or stopped. There is also a pump which can take water from the reservoir to the tank. The capacity of the pump, let it be assumed, is just sufficient to raise water to a height of 10ft. and not more than that. If, now, the tap be opened and the pump started, it will be seen that water is flowing down the pipe from the tank to the reservoir from one side while on the other side water is being raised from the tank *i.e.*, water-flow is taking place continuously along the whole path which is known as the water circuit. Water is coming down from the tank to the reservoir because there is a level difference of about 10ft. between them. If the level difference could be increased, keeping the length of the pipe same, then, the strength

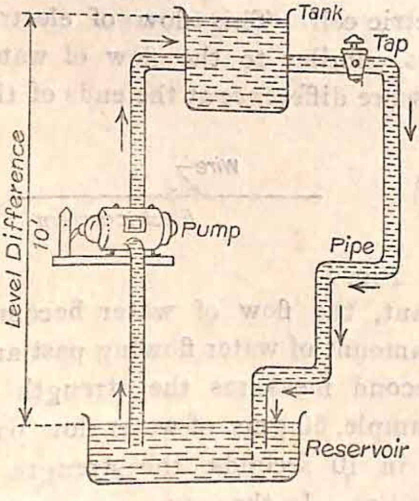


Fig. 2

of water current would be increased. For example, without using any extra pipe, if the bent pipes be straightened and the level-difference be made 20 ft., the strength of water current along the pipe would be doubled. The flow of water in the pipe is, in this case, steady because the level difference between the reservoir and the tank is maintained by pumping water from the reservoir to the tank. From this discussion, it is clear that the *strength of water current depends upon the level difference.*

Same thing happens in the case of electric current. When electric current flows in a circuit, its strength depends upon the difference of electric levels at the two ends of the circuit. In the science of electricity, the electric level is known as *electric potential.* In the case of flow of water, the level difference was maintained by a pump. Similarly, in the case of flow of electricity, the potential difference can be maintained by an electric cell. As soon as the tap in the water-circuit is opened, water begins to flow down from the tank and the pump starts working; similarly in the electric circuit, when the key is closed, current starts flowing in the circuit and chemical reaction starts in the cell. In this connection, it may be mentioned that as water flowing through the pipe gets some resistance, so electric current flowing in a circuit also faces some resistance known as the **resistance** of the circuit.

It may, therefore, be said that potential difference is responsible for the flow of electric current in a circuit. This potential difference is known as the **electromotive force**, abbreviated as E. M. F. of a cell.

2·4. Ohm's law: In the year 1826 G. S. Ohm, a teacher of Physics at Cologne, established a law connecting the current passing through a conductor and the potential difference between the ends of the conductor. It is known as **Ohm's law.** The law may be stated as follows:

Temperature and other physical conditions remaining *same, the current passing through a wire is proportional to the potential difference between its ends.*

Suppose AB is a conducting wire (Fig. 3). The current through it is I and the potentials at the ends A and B are V_A and V_B respectively. Then, according to Ohm's law,

$$(V_A - V_B) \propto I$$

So, if the temperature and other physical conditions (such as length, cross-section, etc.) of the wire be kept unaltered, then, with the increase of its potential difference $(V_A - V_B)$, its current I will increase and vice versa.

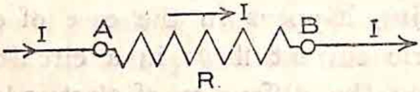


Fig. 3

Now, we can write, $(V_A - V\ ) = R.I$ $[R = \text{a constant}]$

$$\therefore \quad \frac{V_A - V_B}{I} = R$$

The constant R is called the *resistance* of the conductor and it is the ratio of the potential difference (p. d.) across it to the current flowing through it.

2·5. Resistance : The term 'resistance' is very important in electricity and requires detailed discussion. Its significance will be clearly understood if we take up the analogy of water-flow through a pipe as mentioned in art. 2·3.

We have seen that water flows through a pipe if there be a level difference at the two ends of the pipe. If, now the pipe be made wide or narrow or the length of the pipe increased or decreased, keeping the level difference always constant, will the flow of water change ? It is needless to say that flow of water does depend upon the cross-section and the length of the pipe. If the cross-section is increased *i.e.*, for a wider pipe, the strength of the current increases but for a pipe of longer length, the strength of water current decreases. In other words, we can say, wider pipe offers less resistance but longer pipe greater resistance to the flow of water.

Same thing happens in the case of electric current in a wire. The current strength in a wire depends upon the cross-section and the length of the wire, when the p. d. is kept unaltered.

2·6. Factors upon which the resistance of a conductor depends :

The resistance of a conductor depends upon the length, the cross-section and the material of the conductor.

(*i*) The resistance (R) of a conductor is proportional to its length (l) when the material and the cross-section are kept unaltered *i.e.*, $R \propto l$.

(*ii*) The resistance (R) of a conductor is inversely proportional to the cross-section (A) of the conductor when the material and the length are kept unaltered *i.e.*, $R \propto \frac{1}{A}$.

(*iii*) The resistance (R) of a conductor depends on the material of the conductor when the length and the cross-section are kept unaltered.

Thus, $R \propto \frac{l}{A}$ when both length and cross-section vary

or, $R = \rho . \frac{l}{A}$ [ρ = a constant]

The constant ρ is known as the **specific resistance** or **resistivity** of the conductor which depends upon the material of the conductor.

If, in the above equation, we write $l = 1$ cm. and $A =$ 1sq. cm., then $\rho = R$ ohm-cm. We see, therefore, that *the resistivity of a material is numerically equal to the resistance of a conductor made of the material of length 1 cm. and area of cross-section 1 sq. cm. and is expressed in ohm cm. units.*

For example, resistivity of copper is $1·62 \times 10^{-6}$ ohm-cm. means that a cube made of copper, having length, breadth and height each equal to 1 cm., has a resistance equal to $1{\cdot}62\times10^{-6}$ ohm.

Of wires of different metals, having same length and cross-section, silver offers least resistance to current *i.e.*, it has got the greatest conductivity. But silver being very costly, for common use, copper, a close second in respect of conductivity, is widely used.

To prepare a high resistance, ordinarily special alloys like eureka (60% copper, and 40% nickel), manganin (84% copper, 12% manganese and 4% nickel) and nichrome (80% nickel and 20% chromium) are used. The resistance of eureka and manganin is about 25 times and that of nichrome 60 times the resistance of copper.

2·7. Practical units of different electrical quantities :

So far we have not mentioned any unit of electrical quantities like current, potential difference, resistance, etc. The practical unit of current is *ampere*, that of potential difference *volt* and the ratio of volt to ampere—*i.e.*, the resistance of a conductor is expressed in *ohm*. Besides, the practical unit of a quantity of electricity is *coulomb*. Their definitions are as follows :

(*i*) Current strength :

The practical unit of current, as mentioned before, is *ampere*. If 1 coulomb of electricity flows past any section of a conductor in 1 second, the current is said to have a value of 1 ampere. That is,

$$I \text{ ampere} = \frac{Q \text{ coulombs}}{t \text{ seconds}}$$

$$\text{or,}\quad Q = I\times t.$$

(ii) Potential difference and Electro-motive force :

The practical unit of both is *volt*. Two points are said to have a potential difference of 1 volt when one joule of work is done in carrying one coulomb of charge from one point to another.

(iii) **Resistance :**

The practical unit of resistance is *ohm.*

$$1 \text{ ohm} = \frac{1 \text{ volt}}{1 \text{ ampere}}$$

(iv) **Quantity of electricity :**

The practical unit of a quantity of electricity is *coulomb.* One coulomb of electricity is taken to be that quantity which when passed through a solution of silver nitrate, will deposit, as a result of chemical action, ·001118 gm. of silver on the kathode plate.

2·8. Heating effect of current :

The flow of electric current through a conductor always produces heat. This is known as heating effect of current which has many practical applications. The light that we get from electric bulbs, the heat that we derive from electric heater and stove are all domestic uses of heating effect of current while electric arc, arc welding, electric furnace, etc. are industrial applications of it.

Experiment : Set up an electric circuit as shown in Fig. 4. Two cells are connected in series *i.e.,* the positive terminal of one is cnnected to the negative terminal of the other, the free positive and negative terminals of the

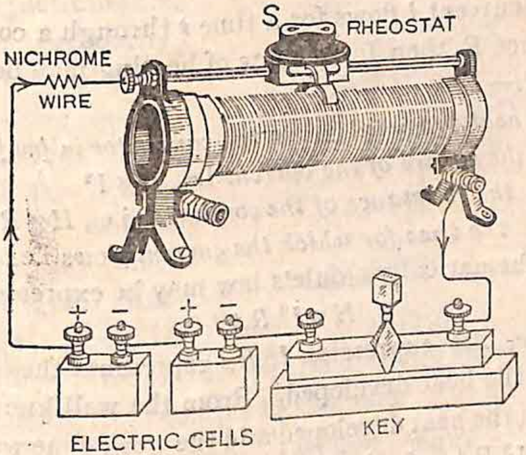


Fig. 4

cells being connected to other apparatus of the circuit, which include a key for starting or stopping the current, a variable resistance (known as rheostat) for increasing or decreasing the current strength and a piece of nichrome wire. The wire should be kept taught in open air.

Place the movable slider S of the rheostat at the extreme left position. This includes the full resistance of the rheostat in the circuit and keeps the current strength minimum. If the key be now closed, current will flow through the nichrome wire. Allowing the current to flow for some time, if the nichrome wire be touched with finger, it will feel hot. Now, move the slider S slowly towards right. The current flowing in the circuit will slowly increase. The nichrome wire will be found to be more and more hot. Finally, it may be made red-hot.

From this simple experiment we come to know that when current flows through a conductor, heat is produced. The law relating to the heating effect of current was first enunciated by Dr. Joule in **1841**, which, after his name, came to be known as Joule's law.

2·9. Joule's law :

If a current I flows for a time t through a conductor of resistance R, then Joule's law of heating may be stated as follows :—

The heat produced (H) *in the conductor is proportional to,*

(i) *the square of the current* i.e., $H \propto I^2$

(ii) *the resistance of the conductor* i.e., $H \propto R$

(iii) *the time for which the current flows* i.e., $H \propto t$.

Mathematically, Joule's law may be expressed as

$$H \propto I^2.R.t$$

Here, the expression $I^2.R.t$ represents the work done and H, the heat developed. From the well-known relation between the heat developed and the work done we can write,

$$I^2.R.t.=J.\,H. \quad [J=\text{mechanical equivalent of heat.}]$$

$$\text{or,}\quad H=\frac{I^2.R.t}{J}$$

So far no units have been mentioned for current, resistance or the heat involved. According to the practical units, if current (I) be expressed in ampere, resistance (R) in ohms, time (t) in seconds and heat (H) in calories, then we can write,

$$H=\frac{I^2.R.t}{4.2}=0{\cdot}24\times I^2.R.t \text{ calories}$$

$[\,J=4{\cdot}2 \text{ joules/calorie}\,]$

2·10. Action of current on a magnet :

When a current flows through a wire, it produces a magnetic field around the wire. It was first discovered by Oersted in the year 1820, when he observed deflection of a magnetic needle placed near a wire carrying a current. This is known as the **magnetic effect** of electric current.

Oersted's experiment : To demonstrate the magnetic effect of current Oersted performed the following experiment.

AB is a straight, horizontal wire set along north-south direction, through which current may flow (Fig. 5). Below it is placed a freely pivoted magnetic needle, which will ordinarily place itself parallel to the wire along north-south direction. This position of the needle is shown by dotted lines in the adjoining diagram (Fig. 5). But as soon as a current is allowed to flow through the wire, the needle gets deflected and sets itself at right angles to the wire.

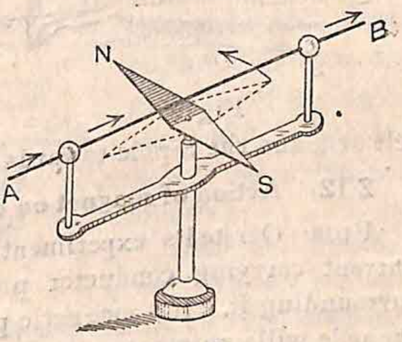


Fig 5

On further investigation, Oersted found that the direction of deflection was reversed if the current was made to flow in the wire in the opposite direction *i.e.*, from B to A or if the wire was set below the magnetic needle.

This experiment, therefore, proves that electric current can produce a magnetic field because a magnetic needle is deflected by a magnetic field alone.

Oersted's discovery made a great impact on the progress of the science of electricity as very many electrical devices ranging from electric bells and telephones to powerful electro-magnetic cranes and motors were devised on the basis of this discovery.

2·11. Rule for the direction of deflection of the needle :

We have seen that the direction of deflection of the magnetic needle depends on the direction of the current and also on whether the wire is above or below the needle. Later Ampere gave a rule, called the *swimming rule* for determining the direction of deflection of the needle.

Ampere's swimming rule :

Imagine a man swimming along the wire in the direction of the current and facing the needle with arms outstretched. (Fig 6) ; then the N-pole of the needle will be deflected towards his left arm and the S-pole towards his right arm.

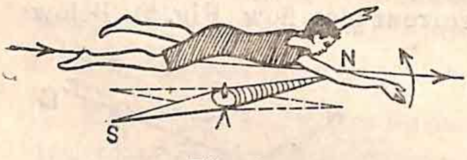


Fig 6

2·12. Action of magnet on current :

From Oersted's experiment, we come to know that a current carrying conductor produces a magnetic field surrounding it. If a magnetic pole be placed in that field, the pole will experience a force of attraction or repulsion and will be deflected from its position. From the law of action and reaction, it follows that the magnetic pole will also exert a force on the conductor due to which the conductor will move towards or away from the pole, if free to move. This is known as the action of magnet on current.

Suppose AB is a straight conductor carrying a current in the downward direction. The lines of force around it would have the direction as shown in Fig. 7. Hence a magnetic north pole placed at P would tend to be driven along a tangential direction to the arc PR. Since reaction is opposite to action, if the pole at P is fixed and the wire AB free to move, the latter will be driven in the tangential direction to the are OX. If the direction of the current in the wire AB be reversed, the deflection would also be reversed.

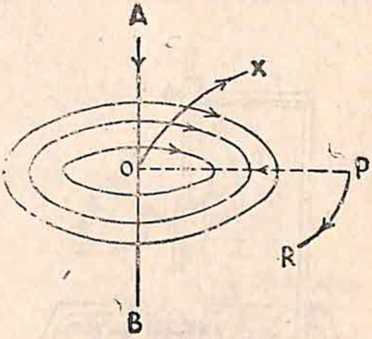


Fig. 7

From this, we conclude that *if a current-carrying conductor be placed in a magnetic field of a fixed magnet, the conductor will experience a force.*

Direction of motion of the wire : Fleming's left-hand rule :

The direction of the mechanical force on the conductor is given by Fleming's left-hand rule. It may be stated as follows :

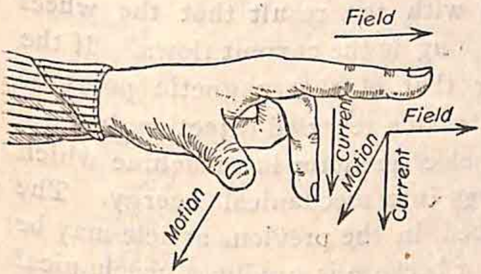


Fig. 8

Hold the thumb, first and second fingers of the left hand so as to be mntually at right angles. If the first finger points to the direction of the field and the second in the direction of the current, the thumb will give the direction of the force on the conductor (hence of the motion) [*Fig.* 8].

2.13 Barlow's wheel :

It consists of a star-shaped wheel made a copper which can rotate in a vertical plane with its points dipping into a pool of mercury kept in a groove on the wooden platform [Fig. 9]. With the help of two terminals, the current is led through the wheel and the mercury and finally to the battery which is connected to the terminals mentioned earlier. A magnetic field is set up at right angles to the wheel-spokes by a U-shaped magnet as shown in the figure. When the switch is closed current flows down the spokes dipping into the mercury and hence a force is exerted on it causing it to move in a direction given by Fleming's left-hand rule.

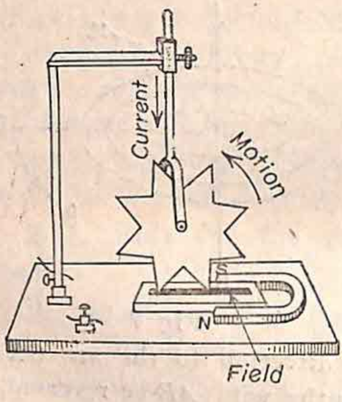


Fig. 9

If the current flows downward, the wheel begins to move in a direction as shown in the figure. As soon as a spoke moves forward, the next spoke due to inertia of motion, dips into the mercury and the same thing happens. This process is repeated with the result that the wheel rotates continuously as long as the current flows. If the direction of current or that of the magnetic poles be reversed, the wheel rotates in a reversed direction, too.

2·14. Motor : An electric motor is a machine which converts electrical energy into mechanical energy. The Barlow's wheel described in the previous article may be called a miniature motor because it produces mechanical rotation at the expense of electrical energy.

A motor consists of a rectangular coil of wire mounted on a spindle so that it can rotate between the pole-pieces of a strong permanent magnet. The coil is called an *armature.* The two ends of the armature are soldered respectively to the two halves of a copper split ring (P,Q), known as *commutator*, which can rotate along with the armature. Two carbon *brushes* are caused to press lightly against the commutator by means of springs and when these are connected to a circuit with a battery and a variable resistance, the coil rotates [Fig. **10**].

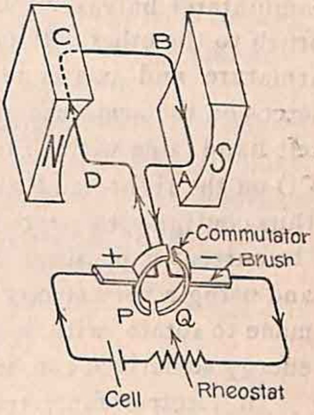
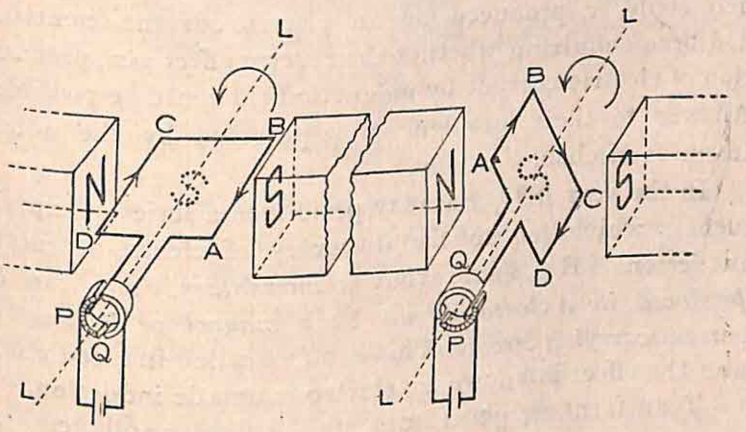


Fig. 10

The principle of action of a motor is illustrated in Fig **11**. Suppose the coil is in the horizontal position when the current is first switched on The current will flow through the coil in the direction DCBA [Fig. **11** (i)] and suppose the segments P and Q are in contact with the positive and negative terminals of the battery respectively. By applying Fleming's left-hand rule, it will be seen that



(i) Fig. 11 (ii)

the arm AB experiences an upward force and the arm CD a downward force. These two forces form a couple which causes the armature-coil to rotate about the line LL as axis in the direction shown in the figure until it reaches the vertical position. In this position the brushes touch the space between the two segments of the commutator and the current is cut off. Due to inertia of motion, the coil moves past the vertical and when this has occurred the two commutator halves automatically change contact from one brush to the other. This reverses the current through the armature and consequently also reverses the direction of forces on the armature arms. The arm AB is now on the left-hand side with a downward force on it while the arm CD on the right-hand side with an upward force. The coil thus continues to rotate in the same direction as long as the current is passing. By increasing the current-strength and using a very strong magnet, the armature coil can be made to rotate with a great speed and the mechanical energy so derived can be utilised in various ways.

In electric fans, tram cars, pumps, rolling mills, etc. electric motors are widely used.

2'15. Electro-magnetic induction :

Ever since Oersted's discovery in 1820, that magnetic field could be produced by an electric current scientists had been enquiring whether the reverse effect *viz.*, production of electric current by magnetic field could be possible. Answer to their problem was provided by the noted inventor Michael Faraday.

In the year 1831, Faraday performed a series of experiments which led to the discovery of electro-magnetic induction. He found that *a momentary e.m.f. can be produced in a closed circuit by a magnet or by another current-carrying circuit.* This e.m.f. is called induced e.m.f. and the effect is known as **electro-magnetic induction.**

Transformers, generators, and other appliances so much necessary for modern industries for generating and distributing electricity on a large scale, are direct applications of Faraday's discovery of electro-magnetic induction.

Current induced by a magnet :

Wind 150 to 200 turns of insulated copper wire on a cardboard tube a few inches long and about one inch in diameter. Keep the coil upright and connect the ends of the coil to the terminals of a sensitive galvanometer (Fig. 12). This instrument, by the deflection of its pointer, indicates the existence of a current in a circuit.

Now, hold a bar magnet above the coil with its N-pole downwards. Insert this pole quickly into the coil and note that the galvanometer pointer gives a momentary deflection. Quickly withdraw the magnet from the coil and note that another momentary deflection, this time in the opposite direction, is registered. Also note that there is no deflection of the pointer if the magnet is simply allowed to remain at rest inside or outside the coil. *A momentary deflection takes place only when the magnet is moving.*

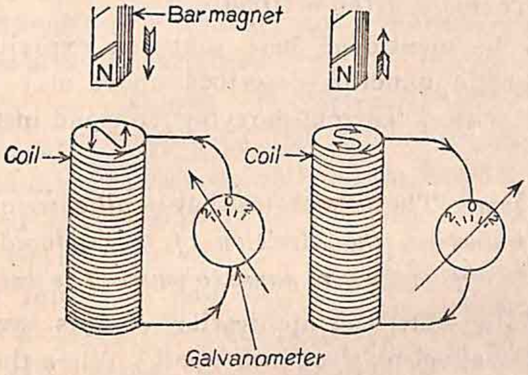


Fig. 12

After much thought Faraday came to the conclusion that current was induced in the coil as a result of the wire being cut by the magnetic lines of force when the magnet moved. Another way of describing this phenomenon is to say that *an e.m.f. is induced only when there is a change in the number of lines of force linked with the coil.*

Carrying out further investigation in this regard, Faraday found that the strength of the induced current depends on: (i) *the number of turns in the coil*, (ii) *the strength of the magnet and* (iii) *the rapidity with which the magnet is inserted into or withdrawn from the coil.*

From all these findings Faraday finally established a law, known as **Faraday's law of electromagnetic induction** which runs as follows:

Whenever there is a change in the magnetic lines of force linked with a circuit, an electromotive force is induced, the strength of which is proportional to the rate of change of the lines of force linked with the circuit.

It may be mentioned here that the experiments of electromagnetic induction described above may also be performed with a current-carrying solenoid instead of a magnet.

Lenz's law: The law states that *in all cases of electromagnetic induction, the direction of the induced current is such as to oppose the very cause to which it is due.*

Fig 12 illustrates the application of this law in the case of a magnet plunged into a coil. When the N-pole of the magnet is inserted into the coil, the induced current must flow in such a direction as to give N-polarity to the end of the coil facing the magnet. Since like poles repel, the motion of the magnet is thus, opposed by the induced current. On the other hand, when the N-pole of the magnet is withdrawn from the coil, the direction of the induced current is reversed. The near end of the coil, now, develops a S-pole and since, unlike poles attract, the motion of the magnet is again opposed.

2·16 Principle of a dynamo:

Modern civilisation is entirely dependent on electric power and for generation and distribution of electric power on a large scale dynamo, is one of the essential machines. There are two types of dynamos: (i) *Alternator* or *A. C. dynamo* which generates alternating current and (ii) *D. C. dynamo* which generates direct current.

A. C. dynamo : Fig. 13 illustrates the construction of a simple form of A. C. dynamo. The machine has a rectangular coil of wire, known as *armature* which is rotated in the magnetic field between the poles of a permanent magnet. This magnet is called the *field magnet*. The ends of the coil are connected to two *slip rings* mounted on the armature spindle. Current is led to the external circuit through two *carbon brushes* which are made to press lightly against the slip rings.

For the rotation of the armature, oil or steam engine is used. In hydroelectric plants, the armature is rotated by the power of water current.

In the experiments of electromagnetic induction described earlier, we have seen that whenever there is a relative motion between the coil and the magnet, a current is induced in the coil. The direction of the induced current when the magnet is plunged into the coil is opposite to the direction of the induced current when the magnet is pulled out of the coil. In a dynamo when the armature rotates, a relative motion is set up between the permanent magnet and the armature coil, due to which a current is induced in the coil. Such relative motion will be maintained as long as the armature coil rotates and the induced current will also continue to flow in the armature coil. Now, during the rotation of the armature, any of its arms, starting from the horizontal position, becomes vertical and then goes to the horizontal position again and finally moves downwards. In other words, during one full rotation any arm moves in a particular direction in one half of its rotation and in the opposite

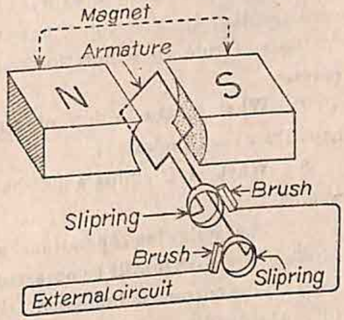


Fig. 13

direction in the other half. As a result, the direction of the current in one half of the rotation of the armature becomes reversed in the other half. In the external circuit, therefore, we will get alternating current.

Exercises

1. State Ohm's law and explain how it leads to the definition of resistance.

2. Explain the practical units of current, potential difference and resistance.

3. What is called electromotive force of a cell ? What is its unit ?

4. What are the factors upon which the resistance of a conductor depends ? What is specific resistance ?

5. State Joule's law in connection with the development of heat in a conductor by electric current. Write an expression for the heat developed.

6. A small compass needle is pivoted on a vertical stand. If a current carrying wire is now placed over the compass needle, how will the needle set itself ? What change in the position of the needle will be observed in the following cases :—(i) the wire is above the needle, (ii) the wire is below the needle, (iii) the direction of the current in the wire is reversed.

State a rule in connection with the deflection of the needle in the above cases.

7. What is the action of a magnet on a current ? Describe a suitable experiment to illustrate it.

8 What is Fleming's left-hand rule ? In what connection is this rule applied ?

9. The following operations are made in a Barlow's wheel. Describe whether any change will be observed in its rotation :—

(i) The current is increased, (ii) the direction of the current is reversed, (iii) the positions of the poles of the magnet are interchanged.

10. You are given a coil of wire, a magnet and a sensitive galvanometer. Describe how you would proceed to demonstrate the phenomenon of electromagnetic induction with their help.

11. State Faraday's law and Lenz's law in connection with the electromagnetic induction.

12. What is a dynamo ? How does it generate electricity ?

13. Explain the working of an electric motor. What is the difference between a motor and a dynamo ?

14. A few questions, with their probable answers are given below. Put √ mark against those answers which you consider most reasonable :

(i) Upon what does the strength of a current depend when it flows in a wire ? *Ans.* Potential difference, resistance, specific resistance.

(*ii*) Upon what factors does the resistance of a conductor depend? *Ans.* Length of the conductor, its material, its cross-section, the medium in which the conductor is kept.

(*iii*) What is the practical unit of a quantity of electricity ? *Ans.* Ampere, Ohm, Coulomb, Volt.

(*iv*) Upon what does heat developed due to the current depend ? *Ans.* The current strength of the conductor, its resistance, its potential difference, time.

(*v*) What is that machine called which converts mechanical energy into electrical energy ? *Ans.* Motor, Dynamo, Barlow's wheel.

(*vi*) What is the basic principle of Barlow's wheel ? *Ans.* Electromagnetic induction, effect of magnet on current, effect of current on magnet,

(*vii*) Upon what factors does electromagnetic induction depend ? *Ans.* No. of lines of force linked with the coil, the rate of change of lines of force, strength of the magnet.

HAPTER THREE

ELECTROMAGNET AND ITS APPLICATION

3·1. Electromagnet : When a substance is magnetised by electric current, it is generally called an electromagnet. Very powerful and big electromagnets are used in factories.

A long, insulated wire wound over a cylinder made of some non-conducting material, each turn being perpendicular to the axis of the cylinder, is called a *solenoid* (Fig. 1). When a current is passed through such a solenoid, magnetic poles, like those of a bar magnet, develop at the two ends of the solenoid. It, then, behaves just like a bar-magnet. This happens due to the magnetic effect of an electric current.

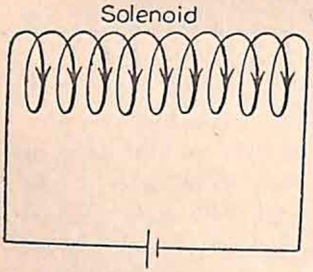


Fig 1

Now, if a bar of soft iron be introduced in the solenoid through which a strong current is passing, the bar is found to be strongly magnetised. This is due to the fact that the current in the solenoid produces a strong magnetic field which, in turn magnetises the soft iron. The combination of the soft iron bar and the solenoid is called an *electromagnet*.

Advantages of an electromagnet over an ordinary magnet :

(i) By increasing or decreasing the current in an electromagnet, the strength of the magnet can be increased or decreased at will. Ordinary magnets do not have this advantage.

(ii) On withdrawal of the current, the electromagnet loses almost all its magnetism but the magnetism of an ordinary magnet is nearly permanent.

(iii) The strength of an electromagnet can be varied, at will, by varying the number of turns of the solenoid. Ordinary magnets do not possess this advantage.

(iv) The poles of an electromagnet can be easily reversed by reversing the direction of the current passing through the solenoid. Such reversal of polarity in an ordinary magent is not possible.

(v) Electromagnets are, in general, more powerful than ordinary magnets.

Electromagnets in practical use :

The electromagnets in practical use, are generally made of soft iron bent into a U-shape [Fig. 2], and having coils of *insulated copper wire wound in opposite directions on the two arms*. This will develop opposite polarities on the two faces of the electromagnet.

Electromagnets are used for a large variety of purposes, some of which are mentioned below :—

(*a*) Electromagnets form essential parts of instruments like electric bell, electric fan, relay system, motor, dynamos, etc.

(*b*) An electromagnet is often used in factories for lifting large masses of iron or removing them from one place to another or for breaking them into pieces first by lifting them to a certain height and then releasing them from that height.

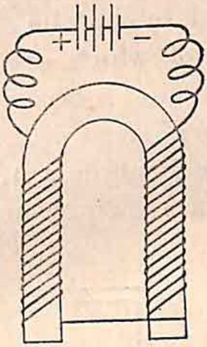


Fig. 2

(*c*) Electromagnets are also used to sort out iron and steel articles from a mixture containing those substances with other non magnetic materials.

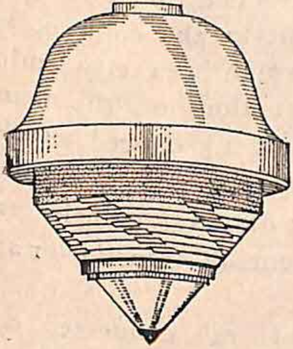


Fig. 3

(*d*) Physicians use electromagnets of special design (Fig. 3) to extract iron or steel splinters from the eye or other parts of the body.

(*e*) Electromagnets are widely used in loudspeaker, telephone, etc. because the strength of its magnetism can be varied by varying the current strength passing through it.

3·2. Telephone system :

By telegraph system, messages can be sent from one place to another with the help of a code known as "Morse code". But in the field of communication, a revolutionary change was ushered in by the discovery of telephone by Alexander Graham Bell in 1876. Telephone can transmit the sound of human voice over long distances.

In original telephone, transmitter and receiver were alike. Such an instrument is shown in figure 4. It consists of a U-shaped magnet formed by placing a short permanent bar magnet *M* across two ends of two soft iron bars *P* and *Q*. This is placed so that it exerts a pull on a springy magnetic alloy diaphragm *A*. Two solenoids are wound in opposite directions on the soft-iron bars, the free ends of which are connected to the line-wires. The diaphragm *A* becomes magnetised under the influence of the permanent magnet *M* When a person speaks in front of the diaphragm *A*, it is set into vibrations. Its movement changes the number of lines of force linked with the coils wound over *P* and *Q* and according to the laws of electromagnetic induction a current is induced in the coils. Due to the presence of the soft iron rods in the coil, the induction becomes very strong. The line wires carry this current to the coils of the receiver, which is exactly similar in construction as the transmitter and a fluctuating magnetic field is produced between the poles of the magnet and the diaphragm of the receiver. As a result, the pull on the receiver diaphragm varies and it vibrates reproducing the movements of transmitter and hence the sound which caused it.

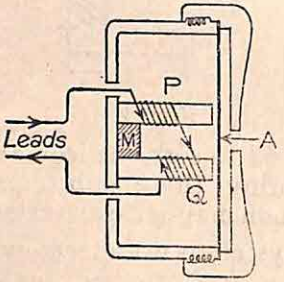


Fig. 4

Line-wires of all the telephones are connected to a central office, known as 'Exchange.' When a person wants to speak to another over the 'phone he asks the 'operator' at the exchange to connect him to the number of the other person. When the connection is made by the operator, the two persons can hear the voice of each other through the 'phone. In a modern telephone system this connection is made automatically as the person in the transmitting end dials the requisite number (Fig. 5).

Fig. 5

The modern telephone receiver is almost the same as that of Bell, but the transmitter has undergone vast improvement and is, now, invariably a *carbon microphone* invented by Edison.

3·3. Carbon microphone :

Bell telephone is not suitable as a transmitter for long distance transmission as it produces very weak current and hence very weak sound. Edison's discovery of the carbon microphone made long distance telephony possible. Fig. 6 shows the construction of such a microphone.

It essentially consists of two polished carbon discs *A* and *B*, placed at short distance apart, the space between them being filled with small carbon granules. The disc *B* is fixed and the disc *A*, which is movable, is connected to a thin aluminium diaphragm. When the diaphragm moves, the disc *A* also moves. The leads are connected to *A* and *B* which go up to the receiver end. Between the transmitter and the receiver there is a battery.

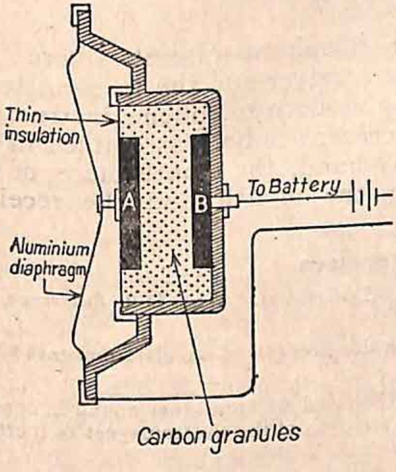


Fig. 6

CHAPTER THREE

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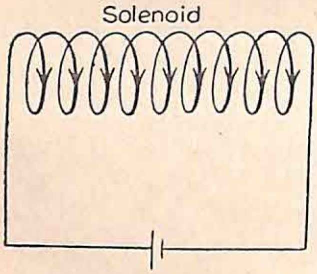

Fig 1

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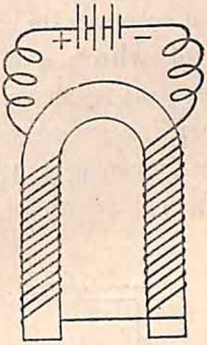

Fig. 2

(c) Electromagnets are also used to sort out iron and steel articles from a mixture containing those substances with other non magnetic materials.

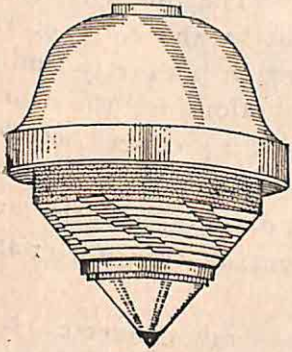

Fig. 3

(*d*) Physicians use electromagnets of special design (Fig. 3) to extract iron or steel splinters from the eye or other parts of the body.

(*e*) Electromagnets are widely used in loudspeaker, telephone, etc. because the strength of its magnetism can be varied by varying the current strength passing through it.

The front portion of the diaphragm is funnel shaped. It is called 'the mouth-piece' of the instrument. When a person speaks into the mouthpiece, the diaphragm moves. When the movement of the diaphragm and the disc *A* presses the granules together, the resistance of the circuit decreases. Outward movement of the diaphragm causes the granules to have only loose contact with one another and to increase the resistance of the circuit. The change of resistance of carbon granules with the change of pressure is a characteristic of carbon for which it is used in carbon microphone. Due to change of circuit resistance, the current supplied by the battery also changes. A fluctuating current corresponding to the movement of the diaphragm, is thus transmitted to the receiver, which actuates the coils in the receiver and causes its diaphragm to vibrate similarly.

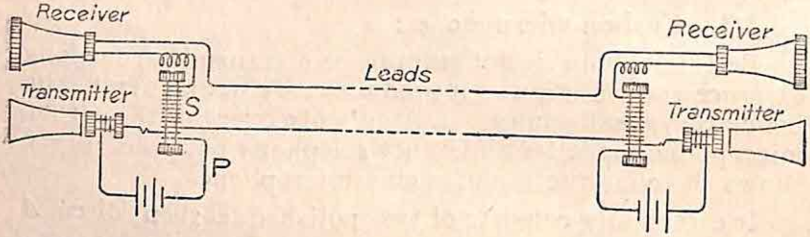

Fig. 7

Fig. 7 shows a simple telephone circuit where the receiver is a Bell telephone receiver and the transmitter is a carbon microphone. In a modern telephone instrument, the transmitter and the receiver are both assembled in one casing so that when held by hand, the mouth-piece of the transmitter remains near the mouth and the receiver near the ear.

Exercises

1. What is an electromagnet? Describe it. What is its difference with a natural or an artificial magnet?

2. What will you do to increase the strength of an electromagnet? For what purposes is it used?

3. Is the wire in the arms of a U shaped electromagnet wound in opposite directions? If so, why? Can the strength of the electromagnet be increased as much as we like?

4. What is a telephone? Describe a telephone receiver.

5. For what purpose is a carbon microphone used? What is the reason of using carbon granules in a carbon microphone?

CHAPTER FOUR

CATHODE RAYS AND X-RAYS

4 1. Electrical conductivity of gases :

Under normal conditions of atmospheric pressure and temperature, most gases are found to be good insulators, *i.e.*, they conduct practically no electricity. Normal air, for example, is almost a perfect non-conductor of electricity, but for which the study of electrical phenomenon would have been an impossibility. All the same, the fact that air does conduct electricity was first demonstrated in 1900 by C. T. R. Wilson. Experiments show that conductivity of gases, in general, increases as the pressure of the gases is decreased. Sir J. J. Thomson, Crookes, Lenard and others conducted experiments to investigate the conductivity of gases at low pressure and found interesting phenomena at every stage of evacuation of the gas.

4·2. Phenomena observed in a discharge tube :

Passage of electricity through a gas or air is known as electric discharge and the tube used for the purpose is called a discharge tube.

The tube generally used to observe discharge phenomena in gases is shown in Fig. 1. It consists of a strong glass tube about 25 cm. long and 5 cm. in diameter closed at both ends and provided with two metal electrodes *A*, and C. There is a side tube *P* provided with a tap, to which an exhaust pump and a low pressure manometer (it can record pressure of the gas) are connected. The two electrodes are connected to a powerful induction coil, capable of giving high potential difference (more than 10,000 volts). The electrode connected to the negative

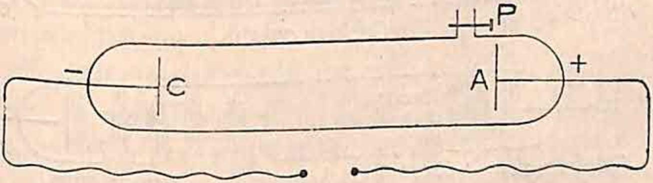

Fig. 1

terminal is known as the *cathode* (C) while the one connected to the positive terminal as the anode (A).

As the pressure of the gas in the discharge tube is gradually reduced by operating the pump, the following series of phenomena are found to take place, one after another, when discharge is passed through it :

(*i*) When the pressure is about 40 m.m. of mercury, irregular violet sparks flash across the tube in a zig-zag way with a crackling noise [Fig. 2(*a*)].

(*ii*) When the pressure is down to about 20 m.m. of mercury, the discharge becomes steadier and the space between the two electrodes is filled up by luminous wavy column with a continuous buzzing sound. The luminous column is called *positive column* [Fig. 2(*b*)], its colour depending upon the nature of the gas inside the discharge

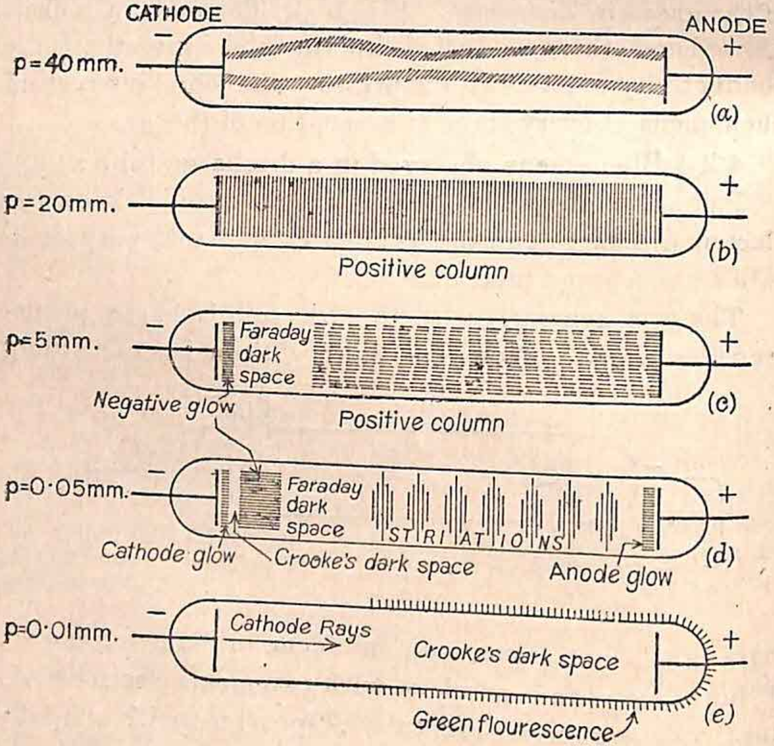

Fig. 2

tube—reddish for air, deep red for neon, bluish white for carbon dioxide, etc.

(*iii*) When the pressure is reduced to 5 m.m. of mercury, the positive column leaves the cathode and advances towards the anode, leaving an ill-defined dark space behind, called the *Faraday dark space* [Fig. 2(*c*)]. At the same time, a bluish glow appears in the neighbourhood of the cathode, known as *negative glow.*

(*iv*) When the pressure is further reduced to about 0·05 m.m. of mercury, the length of the positive column diminishes and that of the Faraday dark space extends. With a slight decrease of pressure at this stage, the negative glow disengages itself from the cathode plate and another dark space, called the *Crookes' dark space*, appears between the cathode and the negative glow [Fig. 2(*d*)]. At this time, the positive column breaks up into bright and dark bands, called *striations.* A blish luminosity appears near cathode and a pink luminosity near anode. The former is known as cathode glow and the latter anode glow.

(*v*) When the pressure is brought down to about ·01 m.m. of mercury, the whole tube becomes occupied by Crookes' dark space and a new phenomenon gradually comes into existence. The walls of the tube—specially the portions opposite to the cathode begin to glow with a bluish or greenish light, depending upon the nature of the glass used. This is known as *fluorescence.* It is caused by the impact of very minute particles, coming out of the cathode plate, against the glass wall. These particles are found to be charged with negative electricity and are called *cathode rays.* [Fig. 2(*e*)].

(*vi*) If the exhaustion is continued further, the discharge has an increasing difficulty in passing until finally the tube refuses to operate.

4·3. **Cathode rays:** It has been pointed out in the previous article that when the pressure in the discharge tube is of the order of 0·01 m.m. the Crookes' dark space practically fills the tube, producing fluorescence on the walls of the tube. The fluorescence is due to a stream of minute particles coming out normally from the surface of the cathode plate. Hence, the stream of particles has been named *cathode rays.* That these particles are negatively charged, fast-moving particles—*the electrons*—was established by systematic investigations carried out by Thomson, Crookes, Perin and others. They also established many other important properties of these rays.

4·4. Different properties of cathode rays :

(*i*) Whatever may be the position of the anode, the cathode rays are emitted normally from the cathode surface.

(*ii*) Like light, cathode rays travel in straight line. If a solid body be interposed in the path of cathode rays, a sharp shadow is formed. In fig. 3, an aluminium sheet in the form of a cross is placed in the path of cathode rays and a sharp shadow of the cross has been formed on the wall behind. Light rays also produce similar shadows of opaque substance placed in their path.

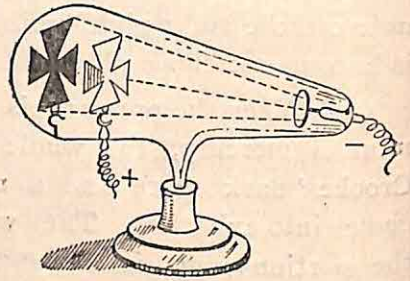

Fig. 3

(*iii*) They can exert mechanical pressure. In fig. 4, a light mica wheel *W* with vanes mounted on an axle is placed on two parallel rails. Now, if cathode rays are allowed to fall on the vanes of the wheel, it will slowly roll towards the anode plate. This shows that cathode rays can exert mechanical pressure.

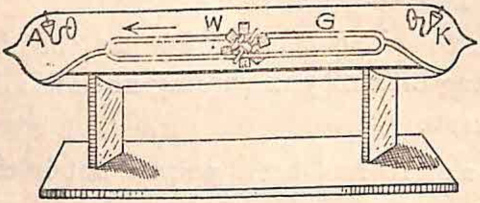

Fig. 4

(*iv*) The rays are able to heat bodies on which they fall. In fig 5, the cathode of the discharge tube is shown concave and at its centre of curvature is placed a piece of platinum. The cathode rays, being emitted normally from the cathode surface are brought to focus at the centre of curvature and hence upon the piece of platinum, which will be rendered red-hot in a short while.

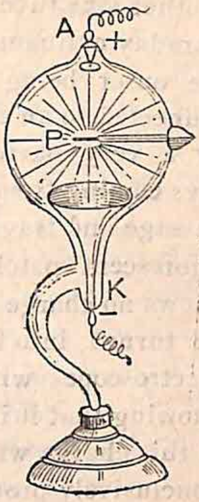

Fig. 5

(*v*) A large number of substances like zinc sulphide, etc, become phosphorescent by the impact of cathode rays.

(*vi*) Cathode rays ionise gases through which they pass.

(*vii*) They are deflected by electric and magnetic fields, and it proves that the particles are electrically charged. The direction of deflection shows that they carry negative charge.

These particles are called *electrons* and the charge carried by each electron is $1{\cdot}6 \times 10^{-19}$ coulomb.

Nature of Cathode rays : That the cathode rays consist of particles carrying negative charge can be said from the direction of deflection of a beam of cathode rays under a magnetic or an electric field. Thomson established this fact by another very simple experiment.

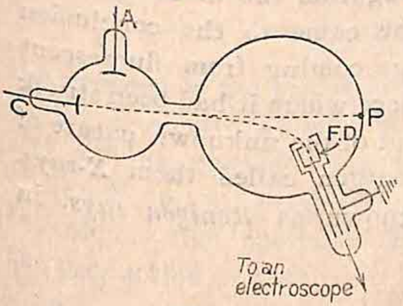

Fig. 6

The apparatus used by him was a discharge tube. It had two bulbs [Fig. 6]. The cathode *C* is sealed in the smaller bulb and the anode *A* in a side-tube. There is another side-tube in the bigger bulb, in which is placed a Faraday cylinder (F. D.). It consists of two cylinders—the outer being earth-connected and the inner being connected to an electroscope. The two bulbs are joined by a very narrow passage. A fine beam of cathode rays coming from the cathode *C* passes through the narrow passage and travelling along a straight line produces a fluorescent patch at *P*. At this time, the electroscope shows no charge in it. If, now, the beam of cathode rays be turned into the Faraday cylinder by a magnet, the electroscope will exhibit a divergence of its leaves, showing that it is charged. An examination of the nature of this charge will reveal that the charge is negative. It conclusively proves that the cathode rays carry negative charge.

4·5. X-rays : In the year 1895, Wilhelm Rontgen, a German physicist experimenting with a discharge tube of high vacuum of the order of 0·01 mm. of mercury or more, found, to his great surprise that a fluorescent screen in the neighbourhood of the tube became luminiscent as if exposed to ordinary light. A photographic plate lying near by was also affected although it was covered up completely by black paper. Rontgen was very much astonished at all these happenings. He thought that some very powerful but invisible ray must be coming from the discharge tube. After further investigations, he came to the conclusion that this invisible radiation was coming from fluorescent glass wall of the tube at the place where it had been struck by the cathode rays. On account of the unknown nature of the new type of radiation, Rontgen called them *X-rays*. The rays were otherwise known as *Rontgen rays*, in honour of their discoverer.

4·6. Production of X-rays :

The arrangement for producing X-ray is ordinarily known as X-ray tube which is shown in Fig. 7.

It is simply a cathode ray discharge tube with certain modifications. The cathode *C* made of aluminium is concave in shape while the anode *A* is usually put in a side tube. Just in front of the cathode, there is another electrode known as *target* or *anti-cathode* (*T*), which is connected to the anode. The anti-cathode is so placed that its surface makes an angle of 45° with the axis of the concave cathode. As a result, the cathode rays shot out normally from the cathode surface, impinge the anti-cathode at one single point. The target or the anti-cathode is made of a metal of high melting point, like platinum, molybdenum or tungsten. When a high potential difference of the order of 30,000 to 50,000 volts is maintained between the anode and the cathode and the pressure of the gas at **0·01** mm. of mercury, cathode rays (*i.e.* electrons) will be produced and when these fast moving electrons are stopped on impact with the target, X-rays are produced. Now-a-days other improved techniques like coolidge tube, betatron, etc. are used for the production of X-rays.

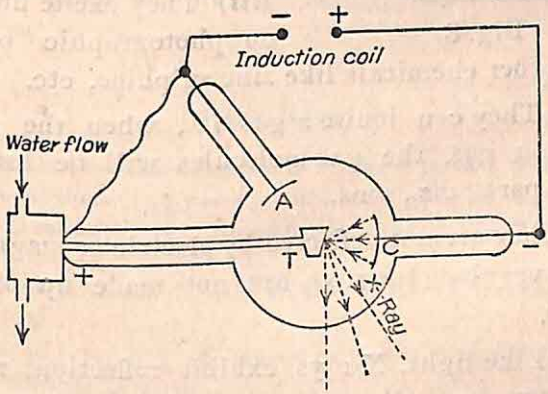

Fig. 7

4·7. Properties of X-rays :

Detailed investigation and analysis of X-rays have revealed the following important properties of these rays :

(*i*) Although they are invisible like cathode rays, they are not material particles; they are waves like ordinary light with extremely small wave-length.

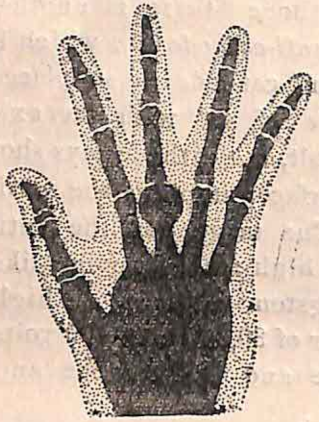

Fig. 8

(*ii*) They can penetrate many substances opaque to ordinary light, for example, aluminium, wood, leather, etc. Human flesh is transparent to these rays while bone is opaque. Fig. 8 shows an X-ray photograph of the palm of a hand. Physicians use this penetrating property for diagnosis of various diseases.

(*iii*) They excite fluorescence on photographic plate and certain other chemicals like zinc sulphide, etc.

(*iv*) They can ionise a gas *i.e.*, when the rays pass through a gas, the gas molecules will be broken into charged parts, *viz.*, ions.

(*v*) They are not deflected by electric or magnetic field. This proves that the rays are not made up of charged particles.

(*vi*) Like light, X-rays exhibit reflection, refraction, interference and all other optical phenomena. As a matter of fact, X-rays and ordinary light belong to the same family, *viz.*, the family of electro-magnetic waves.

4·8. Applications of X-rays :

X-rays have wide applications in various fields, some of which are mentioned below :—

(*i*) *In medical science* : The contributions of X-rays to the medical science are enormous. For treatment of diseases like cancer, tumor, tuberculosis, ulcer, etc. X-rays have been found to be immensely helpful. It is a very effective tool at the hands of the physicians for detecting fracture of bones, existence of undesirable foreign objects inside the body, etc.

(*ii*) *In industry* : In industry, X-ray photographs are used to reveal hidden flaws in metal castings and welded joints.

(*iii*) *In science* : In higher scientific research works, in the analysis of the internal structure of crystals, metals and atoms, etc. X-rays are very often applied.

(*iv*) *In criminological department* : X-rays are now-a-days applied in the police department when thieves swallow any jewel or ornament. They are also used to distinguish false gems from true ones. In customs department, X-rays are used to prevent smuggling of contraband commodities.

Exercises

1. Describe the phenomena observed in a discharge tube when electric discharge is passed through air whose pressure is reduced, step by step.

2. What are cathode rays ? How are they produced ? What are their properties ?

3. Who discovered X-rays ? Why are they so called ? Are they identical with ordinary light ?

4. Describe an X-ray bulb. Mention the different properties of X-rays, Cite a few applications of X-rays.

5. Fill up the blanks in the sentences on the left hand side by selecting suitable words from the right hand side column :—

(a) Under normal condition of pressure and temperature, a gas is not a — of electricity.

(b) Cathode ray particles carry—electric charge.

(c) Although invisible like cathode rays, X-rays are not material particles ; they are —

(d) X-rays are not — by electric or magnetic fields.

(e) Optical properties of X-rays are — with those of ordinary light.

(a) Wave

(b) Deflected

(c) Conductor

(d) Indentical

(e) Negative

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CHAPTER ONE

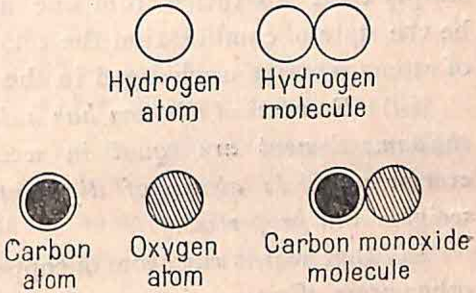
FUNDAMENTAL CONCEPTS

1-1. Molecules and atoms

All matters, be it solid, liquid or gas are nothing but an aggregate of tiny particles, called molecules. Suppose you take a lump of sugar (sugar is a compound composed of three elements carbon, hydrogen and oxygen) and go on dividing and sub-dividing it into smaller and smaller fragments till the smallest independent particles each existing separately from the others and possessing all the properties of sugar, have been reached. On any further subdivision the particles will be no longer sugar, it will break down into constituent elements. These tiniest particles of sugar, which on further subdivision break down into elements are referred to as molecules of sugar. A molecule may, therefore, be considered to be the limit of division of a substance, with the retention of properties of that kind of substance. Hence, a molecule is the smallest possible particle of a substance that can exist in the free state possessing all the properties of that kind of substance. The word *molecule* was coined by Italian physicist Avogadro in 1811. Can you imagine how small a molecule is? You definitely understand how much water is meant by one gram of water. Do you know how many molecules are there in one gram of water? It is 33×10^{21}. What a big number ! If you go on counting at the rate of 1000 molecules per minute then it will take you thousands of years to complete the counting. You can now, at least imagine the astonishing smallness of the molecule, the dimensions of which are far beyond the visibility range of any powerful microscope. The most direct evidence of the real existence of the molecule, however, has of late been obtained with the help of electron microscope, which permits the molecules of some substances to be seen and photographed. Molecules of one and the same substance are all alike, but the molecules of different substances differ. The tremendous number of molecules that may be present in a piece of chalk are all of one kind, identical in weight, dimension and other properties. But a molecule of chalk differs from that of a common salt in all respects.

The word atom is derived from the Greek word '*atomos*' meaning indivisible. The molecules, though have been described as the smallest particles are not indivisible and can be broken down into still smaller particles. These latter particles, which are chemically indivisible are called atoms. Avogadro suggested that the term atom should be restricted to elements. Again suppose that you have divided a piece of gold into many smaller parts. Now if you go on dividing and sub-dividing the smaller pieces they will gradually undergo diminution in weights and volumes. Imagine that in this way you have reached to the limit of division, when no further subdivision is possible. This smallest possible particle i.e., the tiny ultimate speck would still be gold, and nothing but gold and can, therefore, be described as the 'atom' (Greek indivisible) of gold. An atom of an element is defined as the smallest indivisible particle of that element which is capable of taking part in chemical change. An atom is chemically indivisible while a molecule is not. You, perhaps, have understood by this time that a molecule is infinitely small in size. So also is the case with an atom and it requires no further description. Atoms of one and the same element are all alike. The atoms of gold are all identical, while each atom of gold differs from that of silver or iron in weights, dimensions and other properties.

It will not be strictly true to say that the atoms do not exist in the free state. If an atom has its free and separate existence, it is also the molecule of the element. But generally a molecule is formed by the combination of two or more atoms. Molecule of an element is formed by the combination of atoms of one and the same kind. Two hydrogen atoms, for example, combine to form a molecule of hydrogen. **Atomicity** is the number of atoms in the molecule and hence hydrogen molecule is said to be diatomic. Atoms of different element on the other hand form the molecule of a compound. A molecule of carbon monoxide, for example, consists of an atom of carbon and one atom of oxygen. It is evedent from the adjoining figure that a hydrogen molecule on decomposition breaks into two atoms of the same kind i.e., two hydrogen atoms; while in the decomposition of carbon monoxide each of its molecule breaks into two different atoms—an atom of carbon and an atom of oxygen.



1-2. Dalton's Atomic Theory

The idea that all matter is composed of atoms is called atomic theory. As far back as the 6th. century B.C. the ancient philosophers had guessed it. The philosophers of classical antiquity looked to their own intellect for fundamental truth. The atomism was, therefore, a result of contemplative philosophy, a product of their mind They did nothing more and left the idea vague. From the vagueness and the misty realm of philosophy it was John Dalton, a Cumberland school-master, who developed atomic concept into a scientific theory. The laws of chemical combination are experimental facts. These observed facts and a number of others are explained by Daltonian concept. Dalton in 1803 remoulded the classical vague idea in the form of the following postulates, which together make up his atomic theory :

(*i*) *All matter is composed of very minute particles. These particles are indivisible by ordinary chemical means and are called atoms.*

(*ii*) *Atoms can neither be created nor destroyed.*

Thus, creation or destruction of matter is not within the reach of chemical agency. It is only possible to alter the state of combination of a number of atoms ; there may be interchange of attachments between various atoms. Synthesis means the union of atoms, while analysis is simply their separation from one another. But whatever be the state of combination the total number of each kind of atoms remains unchanged in the process.

(*iii*) *Every kind of atom has a definite weight ; atoms of the same element are equal in weight and are all alike in everyway ; while atoms of different elements have different weights and properties.*

In other words any atom of copper would resemble every other atom of copper irrespective of its sources. But each copper atom would differ from each silver atom and so on.

(*iv*) *Compounds are formed by the combination of atoms in definite ratios of whole numbers, usually small.*

That the atoms must combine in whole numbers follows from the very assumption that atom is indivisible.

The smallest particle of a compound substance like water or ammonia was described by John Dalton as 'compound atom'. The smallest particle of an element was called 'simple atom'. As has already been stated, the distinction between atoms and molecules was recognised long afterwards, when Avogadro in 1811 coined the term 'molecule' for the smallest particle of an element or compound that is capable of existing in the free state.

1-3. Atomic and Molecular weights

The atoms and molecules are exceedingly small and so also their absolute masses. One of the heaviest atoms namely the uranium atom has been found to have a mass of $3{\cdot}96 \times 10^{-22}$ gm. only. This single example will make you understand how incredibly light the atoms are. No ordinary weighing machine will do for weighing atoms. Besides, it is highly inconvenient to use such small numbers. Chemists, therefore, adopted the method of comparing the weights of other atoms with that of an atom of hydrogen. Hydrogen atom, the lightest known atom was taken as the standard of comparison, so that the value 1 for hydrogen was chosen as the base. These relative weights are the so-called atomic weights. This provides our definition of atomic weight.

Atomic weight of an element

$$= \frac{\text{Weight of an atom of the element}}{\text{Weight of one atom of hydrogen}}$$

The atomic weight of an element is thus a number representing the relative weight of an atom to the weight of an atom of hydrogen taken as unity.

Later on oxygen was chosen as the standard of comparison and its atomic weight was arbitrarily taken as 16·0000. According to this definition, atomic weight of an element is the number of times an atom of it is as heavy as one-sixteenth of the weight of one atom of oxygen. Atomic weight of chlorine is 35·5 means

$$\frac{\text{Weight of an atom of chlorine}}{\text{Weight of one atom of oxygen}} \times 16 = 35{\cdot}5.$$

Similarly the molecular weight of a substance is the number of times its molecule is as heavy as one-sixteenth of the weight of one atom of oxygen,

$\therefore$ Molecular weight

$$= \frac{\text{Weight of a molecule of the substance}}{\text{Weight of an atom of oxygen}} \times 16$$

Of late, the dominant natural isotope of carbon has been chosen as the standard and this is assigned the value 12. Hence atomic and molecular weights are the relative weights on an arbitrary scale. The atomic weight (mass) unit is defined as exactly $\frac{1}{12}$*th* of the mass of the said carbon atom. Suppose the mass of a carbon atom is x gms, then the unit is $\frac{x}{12}$ gms. Since many elements consist of a mixture of stable isotopes, the atomic weight of an element is the average mass of an atom of the element measured in this unit. One example will make the point clear. Mass of a light hydrogen atom is about 1·0078 units and that of a deuterium atom is 2·0143 units. In ordinary hydrogen there is about (very roughly) one heavy atom to every 5000 light atoms. Because of the extra mass of approximately one unit (2·0143 − 1·0078) of one deuterium atom, the average mass would be $1·0078 + \frac{1}{5000}$ or $1·0078 + 0·0002 = 1·008$, which is the chemical atomic weight of ordinary hydrogen. Let us again come back to the discussion of molecular weight, which may simply be regarded as the sum of the atomic weights of all the constituent atoms of the molecule. The molecular formula of benzene, for example, is C_6H_6 and accordingly the molecular weight of it is $6 \times 12·01 + 6 \times 1·008 = 78·108$.

Gram-atomic weight or simply *a gram-atom* is the number of grams of an element, which are numerically equal to its atomic weight. Atomic weight of oxygen is 16 and 1 gram-atom of oxygen means 16 gms. of oxygen. Similarly 1 gram-atom of hydrogen = 1·008 gm. of hydrogen. *Gram-molecular weight* or a *gram-mole* or simply *mole* (sometimes spelled mol) is the number of grams of a substance (element or compound) which are numerically equal to its molecular weight. Thus, molecular weight of water is 18 and a gram-mole of water means 18 gms. of water. Similarly molecular weight of sulphuric acid being 98, a gm.-mole of sulphuric acid corresponds to 98 gms. of it

By normal density of a gas is meant the mass in grams of a litre of the gas at N. T. P. Normal density of hydrogen, for example, is 0·09 gm. and it means that the mass of one litre of hydrogen at 0°C and 760 mm. pressure is 0·09 gm. Suppose, the molecular weight of a gas or vapour is M and its normal density is D gms./litre. A gram-molecule of the substance, therefore, will occupy at

N. T. P. a volume of $\frac{\text{M gms.}}{\text{D gms./litre}} = V_m$ (say) litre. This V_m is referred to as *gram-molecular volume* or *molar volume.* The volume of 1 gm.-molecule of hydrogen at N.T.P. is $\frac{2{\cdot}016 \text{ gm.}}{0{\cdot}09 \text{ gm./litre}} = 22{\cdot}4$ litres. This can be expressed in another way by saying that 22·4 litres of hydrogen at N. T. P. contains one gram-molecule of hydrogen. A gram-molecule of any gas will necessarily occupy 22·4 litres at N. T. P. A gram-molecule of any substance, if it is possible to be vaporised, will occupy the volume of 22·4 litres at N. T. P. The molar volume or gram-molecular volume of any gas is 22·4 litres. It is the volume (22·4 litres) that contains one gram-molecule of any gas at N. T. P. The mass in gms. of 22·4 litres of any gas at N. T. P. is, therefore, its gram-molecular weight.

1-4. Periodic table

The elements known to date are a little over one hundred in number. Almost everyone is familiar with some of them, while there are many which are rare. Under standard conditions some are solids, some liquids and some gases. Again some show striking similarities among themselves and a great many exhibits a wide variety in their nature at the same time. The compounds too, that the elements form are also varied in nature. The study of chemistry, it is obvious, is not an easy job. To acquire an ordinary level knowledge it is necessary to get acquainted with a great many facts and the theories that connect them. Efforts are being made to make this task as easy as possible. The first attempt in this direction that has long since led to the classification of elements into two broad groups—metals and non-metals—is undoubtedly the simplest one. Though this distinction is useful in many ways yet no sharp line of demarcation can be drawn between the two groups. The existence of several elements referred to as metalloids, that share certain characteristics of both classes is a clear proof of it. With the progress of time scientists began to realise that this classification could not make the task of learning chemistry sufficiently simple. In consequence, attempts were made to arrange elements into smaller groups on the basis of similarities in properties. Early in the nineteenth century many investigators felt the necessity of establishing a relation between the chemical properties of the elements and their atomic weights and classifying the elements on this basis. Döbereiner of Germany in **1817** noticed that the atomic weight of strontium is approximately the arithmetic mean of those of calcium and barium.

Ca 40	Sr 88	Ba 137

$$\tfrac{1}{2}(40+137)=88{\cdot}5$$

These elements closely resemble one another in chemical character and Döbereiner in 1829 asserted that this relationship might be the basis of systematic classification of elements. The elements with similar properties can be arranged in groups by threes, where the atomic weight of the middle element in each group is approximately the arithmetic mean of those of the other two, e.g.,

Cl 35·5	Br 80	I 127

This is referred to as *law of triads*, but it failed to embrace all the then known elements. The first attempt to find a generalisation embracing the atomic weights of all the elements was made by the English chemist Newlands, who arranged the elements in ascending order of atomic weights. Every eighth element in this arrangement, starting from any point is a kind of repetition of the first. The eighth element resembles the first, the ninth resembles the second and so on. Newlands classified the elements into seven columns. A portion of Newlands' table showing classification of elements is given below:

H	Li	G*	B	C	N	O
F	Na	Mg	Al	Si	P	S

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* G (Glucinum) = Be (Beryllium)

Li, C, N, etc for example, resemble very closely the elements Na, Si and P respectively in properties Na is the eighth element if the counting is begun from Li. Similarly Si becomes the eighth element, when the starting point is C and so on. The existence of the periodic behaviour as realised by Newlands though contained the germ of the periodic law, he made the unfortunate mistake of naming his generalisation the *law of octaves*, due to the similarity of this with the musical scale.

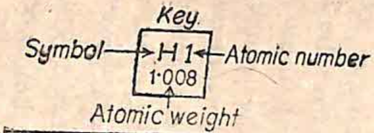
The attempt at systemisation by Dimitri Ivanovich Mendeleev merits special consideration, as no attempt was as brilliant, rational and complete as that of the Russian chemist. First of all, he said, 'the most likely property, that reflects the relation among the elements is the atomic weight peculiar to each element'. The elements, he observed, if set forth in the ascending order of their atomic weights show an evident periodicity of properties. He arranged the elements in terms of increasing atomic weight in such a manner as the like elements fall in the same vertical groups. For example,

Li	Be	B	C	N	O	F
7	9	11	12	14	16	19
Na	Mg	Al	Si	P	S	Cl
23	24	27	28	31	32	35 5

Li and Na or Be and Mg, etc. that come under the same vertical column closely resemble one another. The horizontal rows he described as *periods* and the vertical columns as *groups*. Mendeleev was the first to appreciate fully the significance of periodicity and he went so far to maintain the group similarity as he reversed the order of atomic weights, where necessary. Indeed, he had so much faith in his own scheme that he expressed by generalisation his observations in the form of a law, what he chose to call the *periodic law*. It states that *the properties of elements are a periodic function of their atomic weights.* On the basis of the periodicity the table, that he drew up was called by him the *periodic table*. Later in 1871 a modified form of his previous table was published. In this a more comprehensive treatment of the periodic law was made. The classification of element on the basis of periodic law is known as *periodic classification of elements.* The table of 1871 consists of eight vertical columns in all. Subsequent developments led to its various modifications. One such modification is the inclusion of another vertical column comprising the inert gases such as argon, etc. This group is known as zero group. Besides, Mendeleev left some blank places in his table owing to want of suitable elements to fit in and thus predicted the existence of elements not then discovered. Later on the then unknown elements were not only discovered but their properties were found to agree fairly well with what Mendeleev predicted. The last word is yet to say, as it has been proved what determines the properties of an element is its atomic number and not the atomic weight. This is clearly evident from the existence of isotopes. An element is actually defined by its atomic number. The properties of an element, it is to be noted, are dependent on the structure of the atom and systematically vary with the atomic number. The gradation of chemical properties with atomic number does not progress continuously, it involves a crude periodicity, as the elements with almost identical properties are found at recurrent, though not always equal, intervals. The elements with atomic numbers 2, 10, 18, 36, 54 and 86, for example are inert gases. Similarly atomic numbers 3, 11, 19, 37, 55 and 87 correspond to elements which are all metals and highly reactive. The periodic law is now stated as: *The properties of elements are periodic functions of their atomic numbers*

Description : A short table based on Mendeleev's plan consisting of 92 elements (from hydrogen, atomic number 1 to uranium, atomic number 92) is described here.

It contains seven horizontal rows and nine vertical



PERIODIC TABLE

Period	Series	GROUP I		II		III		IV		V		VI		VII		VIII			0
		a	b	a	b	a	b	a	b	a	b	a	b	a	b				
1	1	H 1 1·008																	He 2 4·003
2	2	Li 3 6·940		Be 4 9·013			B 5 10·82		C 6 12·011		N 7 14·008		O 8 16·000		F 9 19·00				Ne 10 20·183
3	3	Na 11 22·991		Mg 12 24·32			Al 13 26·98		Si 14 28·09		P 15 30·975		S 16 32·066		Cl 17 35·457				A 18 39·944
4	4	K 19 39·10		Ca 20 40·08		Sc 21 44·96		Ti 22 47·90		V 23 50·95		Cr 24 52·01		Mn 25 54·94		Fe 26 55·85	Co 27 58·94	Ni 28 58·71	
	5		Cu 29 63·54		Zn 30 65·38		Ga 31 69·72		Ge 32 72·60		As 33 74·91		Se 34 78·96		Br 35 79·916				Kr 36 83·8
5	6	Rb 37 85·48		Sr 38 87·63		Y 39 88·92		Zr 40 91·22		Nb 41 92·91		Mo 42 95·95		Tc 43 [99·0]		Ru 44 101·1	Rh 45 102·91	Pd 46 106·4	
	7		Ag 47 107·88		Cd 48 112·41		In 49 114·82		Sn 50 118·70		Sb 51 121·76		Te 52 127·61		I 53 126·91				Xe 54 131·3
6	8	Cs 55 132·91		Ba 56 137·36		La 57 † 138·92		Hf 72 178·50		Ta 73 180·95		W 74 183·86		Re 75 186·22		Os 76 190·2	Ir 77 192·2	Pt 78 195·09	
	9		Au 79 197·0		Hg 80 200·61		Tl 81 204·39		Pb 82 207·21		Bi 83 209·00		Po 84 210		At 85 [210]				Rn 86 222
7	10	Fr 87 [223]		Ra 88 226·05		Ac 89 227		Th 90 232·05		Pa 91 231		U 92 238·07							

† Fourteen elements (atomic numbers 58 to 71) known as rare earths are placed together

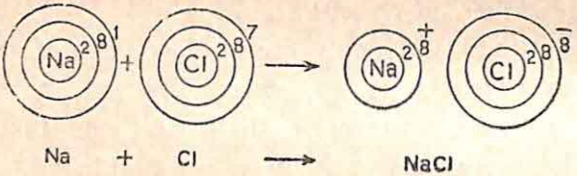
columns. The horizontal rows are called periods and vertical columns groups All the groups from I to VII are each divided into subgroups *a* and *b*. The first period contains only two elements hydrogen (atomic number 1) and helium (atomic number 2) and it is referred to as *very short period*. The second and the third period contain eight elements each, and these periods are known as *short period*. The elements of the third period resemble very closely the corresponding members of the preceding period. Lithium (Li) and sodium (Na), for example, are alkali metals and both decompose cold water. Fluorine and chlorine again are members of the halogen family and each of them combines with metals to form salts. So starting from any element, the ninth element here is a kind of repetition of the first. The elements of the second and third short periods are called *typical* elements. There are eighteen elements in each of the 4th and 5th period, which are referred to as the *first* and the *second long period* respectively. Each of the long periods is again subdivided into *even* and *odd* series. At the every nineteenth element there is a kind of relapse to the starting point Potassium (K) and rubidium (Rb) for example, closely resemble one another. Similar is the case with bromine (Br) and iodine (I). The sixth period containing 32 elements is a *very long period*. The last or the 7th. period is an *incomplete* one and in the present table six elements only have been included, though the elements known todate are a little over one hundred It is to be noted that the each period starts with, disregarding the first one, an alkali metal and ends in an inert gas If sufficient number of new elements of large atomic numbers be discovered in future then the seventh period also will possibly be a *very long period* containing 32 elements and ending in another inert gas, an element of atomic number 118. In the sixth period 14 elements belonging to Group IIIa have been placed together beyond lanthanum (La) and are known as *rare earths*, though they are better designated as *less familiar elements*. In group eight there are nine metals in all ; the elements bearing striking resemblances in groups by threes find places in the fourth, the fifth and the sixth period respectively.

1-5. Electrovalency and covalency :

We have already discussed the electronic structure of atoms. With the information thus available we can proceed to discuss molecular structure. There is no shadow of doubt that the valency bonds by which the atoms are held together in a molecule are related to the electronic structures of the constituent atoms.

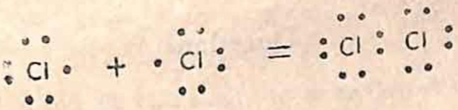
An examination of electronic configuration of atoms of inert gases reveal that all, except helium, have eight electrons in their outermost shell. As the inert gases are highly non-reactive, it may be concluded that an arrangement of eight electrons in the outermost shell is an extremely stable one. One of the postulates of the electronic theory of valency is, therefore, that all other atoms tend to assume the inert gas configuration. The chemical behaviour of atoms is a reflection of this tendency. When atoms combine they try to attain, as far as possible, 8-electron outermost shell. Keeping in view the limitations of the syllabus we shall discuss here only the two types by which atoms can assume such configuration.

(i) It is possible for the atoms of the elements, which are very close to rare gases in the periodic table to assume the stable configuration by transference (i.e., losing or gaining electrons) of electrons. Each of the halogens in the periodic table is followed by an inert gas, while an alkali metal is preceded by an intert gas. An atom of any alkali metal (Li, Na, K, etc.) can, therefore, assume stable inert gas configuration by losing an electron. While a halogen atom can acquire the stable inert gas configuration by receiving an electron. Hence, if an atom of alkali metal transfers one electron to a halogen atom, both the atoms then assume the stable configuration of inert gases and the halide so formed would be a stable one. Atom as a whole is electrically neutral. So by losing or gaining electrons atoms must have a resultant positive or negative charge respectively. These charged particles are called ions and the ions with opposite charges are held together by electrostatic attraction. In the combination of sodium with chlorine sodium atom transfers its outermost electron to the outermost shell of chlorine atom and attains the neon structure, while chlorine atom assumes the argon structure. Sodium atom thus becomes a univalent positive ion Na^+ by losing one electron and chlorine atom becomes a univalent negative ion Cl^- by gaining the electron lost by sodium. In consequence the oppositely charged ions are held together and this is the basis of the valence bond in sodium chloride. This type of link is called *electrovalent link* or *electrovalency*. It may be stated here that atoms can transfer one or more outermost electrons to other atoms so that each becomes a positive or negative ion respectively, often with an 8 electron outermost shell. In the sodium chloride molecule, as stated above both Na^+ and Cl^- ion have an outer octet of electrons. In the reaction between lithium and fluorine the former transfers its outermost electron to the outermost shell of the latter containing seven electrons. Lithium ion possesses helium structure (with two electrons), the fluoride ion being formed with the external octet of neon. A 2-electron shell like the inert gas helium is also a stable arrangement. In the formation of lithium hydride hydrogen atom gains the electron lost by lithium, the lithium and the hydride ions (Li^+, H^-) being formed, with the helium structure.



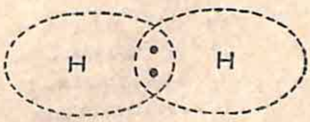
$$\underset{2,1}{Li} + \underset{1}{H} \rightarrow \underset{2}{Li^+}\underset{2}{H^-}$$

(ii) It is difficult to explain in terms of the concept of electro-valency the formation of compounds by elements, which are far off from inert gases in the periodic table. Kossel, who developed the concept of electrovalency, himself recognised that the formation of many molecules could not be fitted into this concept. The important examples of it are the molecules in which decision as to which of the constituent atoms is positive and which negative is puzzling. A second manner whereby atoms can assume stable configuration was postulated by G. N. Lewis and is known as *covalency*: electrons are not actually gained or lost by the atoms involved, they pass into a shared state and sharing involves pairs of electrons. In this way all the atoms concerned complete an octet (or duplet—2-electrons) of outer electrons. The formation of a chlorine molecule, for example, from two atoms of chlorine, each with seven electrons in the outermost shell, may be depicted as follows :



Chlorine molecule

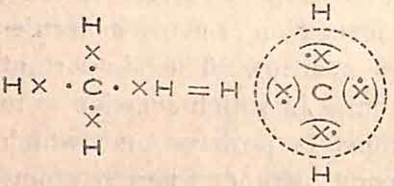
Each chlorine atom contributes one electron to make up a ring of eight but does not entirely part with it. In a molecule of hydrogen each of the two atoms contributes its single electron to make up a ring of 2 and thus by pairing electrons both assume the helium configuration, a shared-electron pair bond being formed between the two. The methane molecule is formed from four hydrogen atoms with one electron each and one carbon atom with four electrons in its outermost shell. By the creation of four shared-pairs of electrons, the carbon atom attains an octet of outer elec-



hydrogen molecule

trons, while each hydrogen atom acquires the stable helium duplet. Towards the formation of each shared pair one electron is contributed by the carbon atom, the other coming from a hydrogen atom. Each shared pair corresponds to one conventional valence bond and it is represented by a single line drawn between the atoms concerned. For example, the structural formula of chlorine molecule, that corresponds to the above electronic structure is Cl—Cl. A double bond is similarly formed by four equally shared electrons between the two atoms concerned. A triple bond involves sharing of three duplets i.e., six equally shared electrons between the two atoms, as is the case with nitrogen molecule.

$$:\mathrm{N}\vdots + \vdots\mathrm{N}: \dashrightarrow :\mathrm{N}\vdots\ \vdots\mathrm{N}: \text{ or } :\mathrm{N}\equiv\mathrm{N}: (\mathrm{N}_2)$$



Methane molecule

Questions

1. Define atoms and molecules. State Dalton's atomic theory.

2. What is meant by : (a) atomic weight, and (b) molecular weight ? What is gram-molecular volume ? Explain with illustrations.

3. Describe in brief the periodic classification of elements.

4. Explain & illustrate the meaning of the terms : (a) electrovalency and (b) covalency.

5. State the difference between the weight of an atom of chlorine and its atomic weight.

State the periodic law.

6. Write short notes on : (a) a gram-atom, (b) a gram molecule and (c) gram-molecular volume.

Sample Questions for objective type tests

Alternate response type

True or False type

(a) An element is really defined by its atomic number.

(b) The molar volume of any gas is 22·4 litres.

(c) The actual weight of an atom of chlorine and its atomic weight are one and the same thing.

CHAPTER TWO

A FEW FAMILIAR ACIDS

2-1. Hydrogen Chloride, HCl

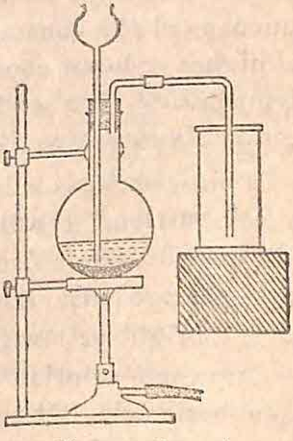
Davy in 1810 proved that it is a compound. As it is a compound of hydrogen and chlorine, it is called hydrogen chloride. It is a gas at ordinary temperature. It is highly soluble in water and the solution is known as hydrochloric acid. In the gaseous state it is also known as hydrochloric acid gas. It is sometimes found to occur in volcanic gases. In small amount (0·2 – 0·4%) it is present in gastric juice.

Laboratory method of preparation—*Principle* : Hydrogen chloride gas is evolved by the action of conc. sulphuric acid on common salt ; volatile hydrogen chloride is being replaced by less volatile sulphuric acid. The reaction takes place in two stages. At first sodium hydrogen sulphate and hydrogen chloride are formed. Then at above 500° excess sodium chloride reacts with sodium hydrogen sulphate to produce a further quantity of hydrogen chloride. But the second step of the reaction is not carried out in the laboratory.

$$NaCl + H_2SO_4 = NaHSO_4 + HCl$$

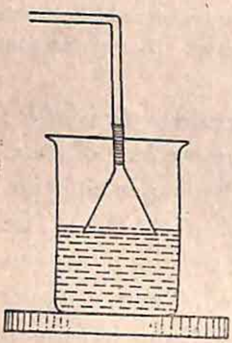
$$NaHSO_4 + NaCl + Na_2SO_4 + HCl$$

Procedure : Take some common salt in a flask fitted with a thistle funnel and a delivery tube as shown in the adjoining figure. Pour in conc. sulphuric acid through thistle funnel so as to cover the whole of common salt and see that the end of the funnel in the flask remains dipped under the surface of the liquid. The reaction starts as the two substances come in contact. When the reaction slackens down, heat the flask gently. Dry the gas that comes out through the delivery tube by passing through a wash bottle (not shown in the figure) cantaining conc. H_2SO_4. Collect



Preparation of hydrogen chloride in the laboratory the dry gas by upward displacement of air. It may be collected over mercury.

In order to prepare an aqueous solution of hydrogen chloride allow the gas that comes out of the flask to come in contact with water through an inverted funnel, the mouth of which should barely dip in the liquid. The gas from the reaction vessel is not directly led into water. The high solubility of hydrogen chloride in water in that case might cause the solution to be sucked back into the hot reaction vessel.



Preparation of aqueous solution of hydrogen chloride

Properties : Hydrogen chloride is a colourless gas with a suffocating, unpleasant smell. It is highly soluble in water ; at 15°, 1 volume of water dissolves 458 volumes of it. Concentrated hydrochloric acid of commerce is about 39% strong. This acid, an boiling loses HCl molecules and becomes weaker : it goes on till it contains only 20·2 per cent of HCl. Acid of this concentration (i.e., 20·2% HCl) distils unchanged at a constant temperature of about 110°C Acid of higher or lower concentration than this boils at a lower temperature. If a weaker acid be boiled, the concentration gradually increases till it contains 20·2% of HCl.

Hydrogen chloride is neither combustible nor a supporter of combustion. If a lighted taper be introduced into a jar full of hydrogen chloride, the taper extinguishes and the gas does not burn. But burning sodium continues to burn with a bright yellow flame : $2Na+2HCl=2NaCl+H_2$.

Aqueous solution of hydrogen chloride is a strong monobasic acid. It turns blue litmus red. Many metals such as aluminium, zinc, iron. magnesium, etc. dissolve in the acid with the evolution of hydrogen : e.g., $Zn+2HCl=ZnCl_2+H_2$. But the acid does not attack the noble metal such as gold or platinum. Aqua regia, however, can dissolve them. Hot concentrated hydrochloric acid dissolves copper powder, hydrogen being evolved. Only in presence of air or oxygen silver is attacked by hydrochloric acid ; $4Ag+4HCl+O_2=4AgCl+2H_2O$.

In being an acid reacts with basic subtances with the formation of salt and water ;—many oxides or hydroxides dissolve in hydrochloric acid :

$$NaOH+HCl=NaCl+H_2O, \; CuO+2HCl=CuCl_2+H_2O ;$$
$$Ca(OH)_2+2HCl=CaCl_2+2H_2O.$$

In presence of traces of moisture hydrogen chloride combines directly with ammonia to form ammonium chloride : $NH_3+HCl=NH_4Cl$.

Towards oxidising agents like manganese dioxide, lead dioxide, potassium permanganate, etc. hydrochloric acid behaves as a reducing agent. Chlorine is evolved, when hydrochloric acid is boiled with manganese dioxide. But potassium permanganate oxidises the acid at room temperature with the liberation of chlorine :

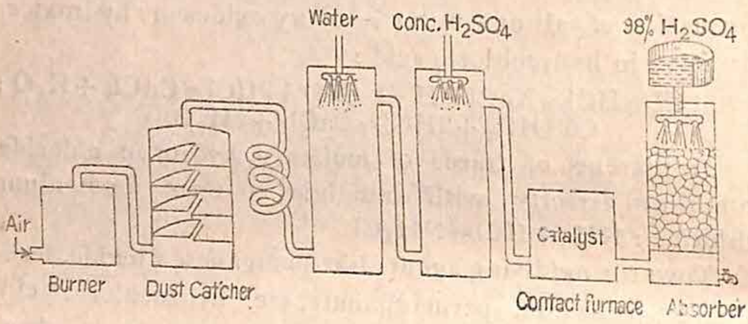
$$4HCl+MnO_2=Cl_2+MnCl_2+2H_2O ;$$
$$16HCl+2KMnO_4=2KCl+2MnCl_2+5Cl_2+8H_2O.$$

Chlorides of metals are generally soluble in water. Common exceptions are those of silver, lead and mercurous mercury.

2-2. Sulphuric Acid, H_2SO_4

Sulphuric acid is one of the most important chemicals known to-date and it is one of the rare compounds that were known long ago. There are two processes for the manufacture of sulphuric acid, the *chamber* process and the *contact* process. But the older method the chamber process is gradually being replaced by the more modern method, the contact one.

Contact process : Sulphur or pyrites are burnt in an excess of air and the gaseous products consisting of a mixture of sulphur dioxide and excess air are allowed to pass through dust catcher whereby the suspended dust particles present in the gaseous mixture settle down. The partly purified mixture is cooled down by passing through a lead pipe and washed with water in towers by counter current movement—the gas flows from the bottom of the tower towards the top while water is sprayed downward from the top. The gas is dried in a similar way by the downward spray of concentrated sulphuric acid. The gases thus dried and purified are led into the contact furnace, the temperature of which is maintained at about 450°. Here oxygen of the air oxidises



Sulphuric acid by contact process

sulphur dioxide to trioxide in presence of platinised asbestos: $2SO_2+O_2\rightleftharpoons 2SO_3$. The reaction being exothermic once the reaction is started no external heating is required. Now-a-days in most plants a substitute. which is a preparation from vanadium pentoxide is employed as catalyst, although it is somewhat less effective than platinum. Because it is comparatively cheap and is less sensitive to poisons such as arsenic oxide, dust particles, etc. than platinum. Sulphur trioxide thus formed, is cooled and then asborbed by a downward heavy stream of 98% sulphuric acid. The water present in the acid: reacts with sulphur trioxide forming sulphuric acid: $SO_3+H_2O=H_2SO_4$. The product is continuously diluted means of a weaker acid or water to maintain the strength at 98% and so the acid of this strength is increased in quantity. The above stated change ($SO_3\rightarrow H_2SO_4$) is also exothermic and the heat is continually removed by passing through cooling pipes placed in water. A portion of the 98% acid is recirculated to the absorption tower and the rest in run off for storage and sale.

Properties : Pure sulphuric acid is a colourless, heavy, oily liquid. Its Sp g. is 1·84. It mixes with water in all proportions. If the acid is to be diluted, pour the acid into water (and never water into acid), a little at a time with constant stirring.

Conc. sulphuric acid is used as a desiccating agent in the laboratory because of its strong affinity for water. Gases, which do not react with the acid may be dried by bubbling through it. Concentrated acid decomposes some organic compounds by abstracting elements of water from it. If formic acid be dropped into hot acid, carbon monoxide evolves : $HCOOH + H_2SO_4 = CO + [H_9O + H_2SO_4]$.

Concentrated sulphuric acid if added to a strong solution of sugar, the whole mass turns black ;—sugar molecule decomposes, carbon particles separate out :

$$C_{12}H_{22}O_{11} + H_2SO_4 = 12C + [11H_2O + H_2SO_4]$$

Sulphuric acid is a dibasic acid. Many metals such as magnesium, zinc, iron, etc. dissolve in dilute acid with the evolution of hydrogen ; $Zn + H_2SO_4 = ZnSO_4 + H_2$. It forms two series of salts—acid salt and normal salt ; $NaOH + H_2SO_4 = NaHSO_4 + H_2O$ $NaHSO_4 + NaOH = Na_2SO_4 + H_2O$.

If the acid vapour is allowed to pass through strongly heated platinum or quartz tube or the acid be allowed to fall in drops into the red hot platinum flask, it decomposes into sulphur dioxide, steam and oxygen : $2H_2SO_4 = 2SO_2 + 2H_2O + O_2$

Strong acid, particularly in hot condition, is an effective oxidising agent. It oxidises carbon and sulphur to carbon dioxide and sulphur dioxide respectively : $C + 2H_2SO_4 = CO_2 + 2SO_2 + 2H_2O$; $S + 2H_2SO_4 = 2H_2O + 3SO_2$.

Most metals dissolve in hot concentrated acid ; metal gets oxidised and the acid is reduced to sulphur dioxide :

$$Cu + 2H_2SO_4 = CuSO_4 + 2H_2O + SO_2.$$

Compounds like hydrogen sulphide, hydrogen bromide, etc. are also oxidised by the acid : $2HBr + H_2SO_4 = Br_2 + 2H_2O + SO_2$; $H_2S + H_2SO_4 = S + SO_2 + 2H_2O$.

2-3. Nitric Acid, HNO_3

The old name for this compound was 'aqua fortis' meaning strong water ; as almost all metals and many other substances are attacked by it. It was first prepared by distilling together nitre or saltpetre KNO_3 and ferrous sulphate $FeSO_4, 7H_2O$. Nitric acid in traces is found in the air in the free state. Lightning causes the combination of nitrogen and oxygen of the air. Nitric oxide thus formed changes to nitric acid by reaction with oxygen and water The acid on being carried down to the soil by the falling rain fertilises the latter. In the soil it is mainly found in the combined state as nitrate. Large deposits of sodium nitrate, for example, are found in Chile, South America.

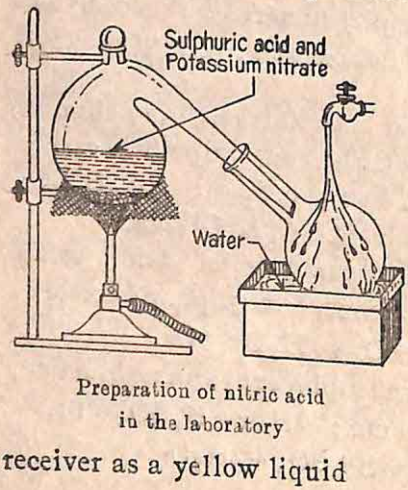
Laboratory method of preparation : *Principle* : Nitric acid is prepared in the laboratory by the action of less volatile sulphuric acid on sodium or potassium nitrate. This reaction is completed in two stages.

At first, (*a*) $KNO_3+H_2SO_4=KHSO_4+HNO_3$ occurs and then with excess of nitrate and at a higher temperature (800°) more acid is obtained due to :

(*b*) $KNO_3+KHSO_4=K_2SO_4+HNO_3$.

But at this high temperature much of the nitric acid is decomposed : $4HNO_3=4NO_2+2H_2O+O_2$. Secondly the normal sulphate (*e.g.* K_2SO_4) that forms a hard coating inside cannot be easily removed. Besides, wear and tear being considerable the vessel may give way at the high temperature. Nitric acid is, therefore, prepared in the laboratory by the first step of the reaction, carried out at about 200°.

Procedure : Take equimolecular amounts of potassium nitrate and concentrated sulphuric acid in an all glass retort. Fit its spout into a flask acting as the receiver, which is placed in water and is kept cold by running water from a tap Heat the retort on a wire gauze gently (200°) by means of Bunsen flame. when nitric acid distils over and collects in the receiver as a yellow liquid



Preparation of nitric acid in the laboratory

Some water and oxides of nitrogen specially the nitrogen dioxide from decomposition of nitric acid are present in this acid. The dioxide colours it yellow. This acid may be concentrated to 98% by distilling with concentrated sulphuric acid. The yellow acid is decolourised by warming to 60°–80° and blowing dry air through it. When the 98% acid is frozen, colourless crystals (m p. $-41{\cdot}3°$) separate out

Properties: Nitric acid is a colourless, fuming, corrosive liquid. It possesses a strong suffocating odour. It is miscible with water in all proportions. Most of the nitrates are soluble in water. Nitric acid containing a fair amount of dissolved nitrogen dioxide is referred to as 'fuming nitric acid.'

It is a strong monobasic acid. dissociating completely into ions, when diluted: $HNO_3 \rightleftharpoons H^+ + NO_3^-$. It turns blue litmus red and neutralises bases to form salts known as nitrates. Copper oxide, potassium hydroxide, Zinc hydroxide, etc., for examples, are converted into the nitrates of the metals concerned:

$CuO + 2HNO_3 = Cu(NO_3)_2 + H_2O$, $KOH + HNO_3 = KNO_3 + H_2O$, $Zn(OH)_2 + 2HNO_3 = Zn(NO_3)_2 + 2H_2O$.

Nitric acid is a strong oxidising agent. Various substances, elementary or compound undergo oxidation by the action of the acid. Heated saw dust is set on fire by concentrated acid and the burning charcoal burns brightly in contact with it: $C + 4HNO_3 = CO_2 + 4NO_2 + 2H_2O$, *i.e.*, carbon is oxidised to carbon dioxide. Iodine, sulphur and phosphorus are oxidised to iodic, sulphuric and phosphoric acid respectively:

$$3I_2 + 10HNO_3 = 6HIO_3 + 10NO + 2H_2O\ ;$$
$$S + 6HNO_3 = H_2SO_4 + 6NO_2 + 2H_2O\ ;$$
$$P_4 + 10HNO_3 + H_2O = 4H_3PO_4 + 5NO_2 + 5NO.$$

Concentrated nitric acid oxidises ferrous salt into ferric salt and sulphur dioxide into sulphuric acid. It liberates iodine from potassium iodide and sulphur from hydrogen sulphide:

$6FeSO_4+3H_2SO_4+2HNO_3=3Fe_2(SO_4)_3+2NO+4H_2O$; $SO_2+2HNO_3=H_2SO_4+2NO_2$; $6KI+8HNO_3=3I_2+2NO+6KNO_3+4H_2O$; $3H_2S+2HNO_3=3S+2NO+4H_2O$,

The pure acid undergoes slow decomposition on exposure to light at room temperature and heating causes it to occur rapidly. Nitrogen dioxide, oxygen and water are formed thereby : $4HNO_3=4NO_2+O_2+2H_2O$.

Save and except a few metals such as gold, platinum, etc. almost all metals are attacked by the acid. Nitric acid acts both as an acid and oxidising agent. Only magnesium and manganese liberate hydrogen from cold and very dilute nitric acid. Chromium and iron are rendered passive by the action of concentrated acid. Cold nitric acid hardly attacks aluminium Besides, of the metals some are, however, converted into their oxides and the rest into the corresponding nitrates. A portion of the acid in the reaction is reduced to oxides of nitrogen (NO_2 NO and N_2O) free nitrogen, hydroxylamine and even to ammonia. In fact, the nature of the metal, concentration conditions of the acid, temperature and the presence of the products of reaction decide what products will be obtained. Below is given a list of reactions with necessary equations :

Copper : (i) Hot and concentrated acid is reduced to nitrogen dioxide : $Cu+4HNO_3=Cu(NO_3)_2+2H_2O+2NO_2$.

(ii) Cold and moderately concentrated (1 : 1) acid is reduced to nitric oxide :

$$3Cu+8HNO_3=3Cu(NO_3)_2+4H_2O+2NO.$$

(iii) Cold and dilute acid is reduced to nitrous oxide :

$$4Cu+10HNO_3=4Cu(NO_3)_2+5H_2O+N_2O.$$

Zinc : (i) Hot and concentrated acid is reduced to nitrogen dioxide :

$$Zn+4HNO_3=Zn(NO_3)_2+2H_2O+2NO_2.$$

(ii) Cold and moderately dilute (1 : 1) acid is reduced to nitric oxide : $3Zn+8HNO_3=3Zn(NO_3)_2+4H_2O+2NO$.

(iii) Cold and dilute acid is reduced to nitrous oxide :

$$4Zn+10HNO_3=4Zn(NO_3)_2+5H_2O+N_2O.$$

Ammonium nitrate is also obtained by the action of cold and very dilute acid :

$$4Zn+10HNO_3=4Zn(NO_3)_2+3H_2O+NH_4NO_3.$$

Iron : (i) Hot and dilute acid is reduced to nitric oxide mainly : $Fe+4HNO_3=Fe\ NO_3)_3+2H_2O+NO$.

(ii) Ammonium nitrate is obtained by the action of cold and dilute acid :

$$4Fe+10HNO_3=4Fe(NO_3)_2+3H_2O+NH_4NO_3.$$

Aqua-regia : A mixture of one volume of concentrated nitric acid and four* volumes of concentrated hydrochloric acid is known as '*aqua-regia*', as it can dissolve gold, the king of metals :

$$Au+4HCl+HNO_3=HAuCl_4+NO+2H_2O.$$

Neither of the acids alone can do the same.

Aqua regia on warming gives off an orange yellow mixture consisting of chlorine and nitrosyl chloride :

$$HNO_3+3HCl=Cl_2+NOCl+2H_2O.$$

Questions

1. How is hydrogen chloride prepared in the laboratcry ? State its inportant properties.

2. Describe in brief a method of preparing hydrochloric acid. Mention one of its physical and two chemical properties.

3. Describe a method of preparing sulphuric acid on a large scale. State two of its physical and three chemical properties.

4. How is nitric acid prepared in the loboratory ? Mention its chief properties.

5. Mentioning the necessary condition state with plausible equations the actions of :—

(a) Sulphuric acid on S, Zn and HBr ;
(b) hydrochloric acid on Ag, MnO_2 and $KMnO_4$; and
(c) nitric acid on I_2, $FeSO_4$ and Cu.

Sample questions for objective type tests

A Alternate response type

Yes or No type

(i) Is sulphuric acid less volatile than hydrochloric acid ? —
(ii) Is hydrochloric acid an oxidising acid ? —
(iii) Is sulphuric acid a dibasic acid ? —

B. Multiple choice type

(i) Which of the following reagents will liberate chlorine from hydrochloric acid at room temperature ?

—Manganese dioxide, patassium permanganate.

(ii) Which of the acids is used as desiccating agent in the laboratory ?

—Conc. HCl, Conc. H_2SO_4, Conc. HNO_2.

(iii) Below is given a list of metals ; select one from it in order to liberate hydrogen from nitric acid :

—Magnesium, zinc. iron. aluminium,

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*Partington

CHAPTER THREE

A FEW ELEMENTS AND INORGANIC SUBSTANCES

3-1. A few elements

(a) Boron

Symbol B   Atomic number 5   Atomic weight 10·82

Boron does not occur in the free state. It is found only as compounds in nature. Two such compounds of prime importance are boric acid H_3BO_3 and borax $Na_2B_4O_7, 10H_2O$.

Boron in traces is congenial to the growth of plants. Many agricultural crops such as tobacco, cotton etc. require small amount of boron compounds in the soil for their normal growth and in consequence boron fertilizers are gradually gaining wider applications. Boron carbide (B_4C), a compound of boron and carbon is almost as hard as diamond and finds extensive use as an abrasive. Borax finds application in glass industry and as a flux in welding metals. Boric acid is a well known antiseptic and boranes are excellent rocket fuels.

(b) Carbon

Symbol C   Atomic number 6   Atomic weight 12

Carbon is one of the well known elements, constantly met with as coal, wood charcoal etc. in our everyday life. Carbon in the free state occurs crystalline as diamond and graphite and amorphous as anthracite coal. In the combined state it is found in nature in abundance and it is no over-statement to say that in this form it is almost all pervasive. In air it is present as carbon dioxide. Carbonates such as limestone, magnesite, dolomite etc. are important minerals. It is an important constituent of all animals and plant bodies.

Allotropy and allotropes : Some elementary substances may exist in more than one form exhibitting more or less different properties. The different forms are called allotropes and the element is said to exhibit allotropy. Hence, allotropy is the name given to that property of an element by virtue of which it can exist in more than one form. Carbon, sulphur and phosphorus are some of the common examples of the elements exhibitting allotropy. The different allotropes of the elementary substance carbon are described below :

Carbon exists in both crystalline as well as so called amorphous forms.

Carbon

Crystalline
- (i) Diamond
- (ii) Graphite

Amorphous
- (iii) Charcoals { Animal charcoal, wood charcoal etc.
- (iv) Lamp black or soot
- (v) Gas Carbon
- (vi) Coke

Bright, hard diamond ; grey soft graphite and the black charcoal bear no external resemblances to each other and thus boundless is the limit of our astonishment when we think that carbon is the common name for these and a number of substances mentioned above. But if the different varieties are burnt in oxygen, the one and the same substance carbon dioxide turning lime water milky is obtained in each case. Moreover, if each in the pure state and in equal amounts be completely burnt in oxygen the weight of carbon dioxide formed in each case is found to be exactly the same.

Diamond, the hardest substance known is used as gems. Black or dark coloured diamonds—carbonado and boart are of no value as gems and are used for cutting diamonds drilling rocks and polishing other stones.

Graphite is used in the preparation of so called 'lead pencils', crucibles that can resists high temperature, electrodes etc.

Charcoals : Several varieties dependent on the sources are known. Wood charcoal and animal charcoal, for examples, are obtained by dry distillation of wood and animal matters (such as bones etc.) respectively. Wood charcoal is used as fuel, as a reducing agent, for preparing gun powder etc. Animal charcoal is used for decolourising sugar syrup and activated charcoal, a specially prepared one is used in gas masks.

Lamp black is used in printing ink, shoe polish etc.

Gas carbon is used for preparing brushes used in motors and dynamos.

Coke is used as a household fuel and hard coke is used as a reducing agent in the extraction of some metals.

(c) Phosphorus

Symbol P Atomic number 15 Atomic weight 30·97

Dr. Henning Brand, an alchemist of Hamburg in Germany discovered it near about 1674. Phosphorus, the 'light bearer' is so named because of its property of glowing in the dark.

It does not occur free in nature but is always found in the combined state. As phosphate it is abundant and also found in many places. Calcium phosphate, the chief compound occurs in minerals *apatites* and in the bones of animals. It is one of the essential constituents of nerves and brain ; yolk of eggs also contains phosphorus—in all these phosphorus being present in the form of complex organic compounds.

Phosphorus, like carbon exhibits allotropy. Two main forms are : (i) White or yellow phosphorus and (ii) red phosphorus. Two forms differ in many of their physical and chemical (colour, melting point, and in the readiness to react etc.) properties. White phosphorus is metastable and tends to change into the stable variety, red phosphorus. But at ordinary temperature and in the dark the change takes place very slowly Red phosphorus is prepared by heating white phosphorus at 240° in an atmosphere of carbon dioxide or nitrogen. A little iodine catalyses the change. But the change in the reverse direction cannot be effected except by vapourising the red phosphorus. A piece of red phosphorus is taken in a hard glass tube fitted with a rubber stopper, through which are introduced two tubes. Red phosphorus is then heated in a very slow stream of dry carbon dioxide after displacing the whole of air from inside. White phosphorus condenses in the upper cooler portion of the test tube.

That the two forms consist of phosphorus and nothing else will be evident from the following :

(i) White form is changed into the red one in absence of any second substance with which the phosphorus could possibly react. (ii) The different forms if burnt in an excess of pure oxygen, the same substance phosphorus pentoxide is obtained in both the cases. (iii) If identical weights of the two forms are completely burnt in oxygen, the weight of the product phosphorus pentoxide is found to be the same in each case.

Phosphorus is in large demand in match industry. In a 'safety match' the side of the box is coated with a mixture containing powdered glass, red phosphorus and glue. White phosphorus is used for preparing red phosphorus, phosphorus pentoxide, calcium hypophosphite, incendiary bombs etc. It is also used to some extent as a rat poison.

(d) Sulphur

Symbol S Atomic number 16 Atomic weight 32·06

Sulphur had been known from the earliest antiquity. It was once called 'Brimstone' meaning 'burning stone' and people considered it to be the symbol of Devil. Lavoisier was the first to realise in **1777** its elementary character.

In nature it is found both in free and combined state. Free sulphur is often found in the vicinity of volcanoes. There are large deposits of the free elements in Japan, Sisily etc. But most of the sulphur of commerce now comes from Texas and Louisiana in U. S. A., where vast deposits of elementary sulphur of 99·5% purity occur several hundred feet below the surface. As compounds it is abundant in the form of inorganic sulphides and sulphates in various minerals. e.g. as sulphides in iron and copper pyrites (FeS_2 ; Cu_2S, Fe_2S_3), galena (PbS) etc ; as sulphate in gypsum ($CaSO_4.2H_2O$), Kieserite ($MgSO_4.H_2O$) etc. Moreover, it is a constituent of some form of organic matter —onion, garlic, egg etc. are some of the examples of it. Characteristic odour of onion or garlic or blackening of silver spoon by eggs in due to sulphur compounds.

Sulphur is used in the manufacture of sulphuric acid. It is also much in demand in rubber industry. It is employed for dressing vines to prevent the growth of certain kinds of fungus. It finds uses in the preparation of matches, fire works, medicinals etc. It also comes into the preparation of carbon disulphide, which is an important solvent and of calcium bisulphite used in sterilising beer casks and in the manufacture of wood-pulp.

3-2. Some inorganic substances

(*a*) *Common salt* : The salt that we take everyday along with our food is known as common salt and it is essential for the nourishment and growth of our body. With ice it is used as a freezing mixture. It is used for preparing metallic sodium, caustic soda, sodium carbonate, hydrochloric acid, chlorine etc. It is also employed as a preservative for fish and meat.

It is a compound of sodium and chlorine and its formula is $NaCl$.

It occurs in sea water to the extent of 2·6% and in tropical countries like India it is obtained by evaporating the same. In some countries it is primarily obtained from mines. Stassfurt salt deposits in Germany .and Wieliczka salt-bed in Poland are noteworthy. The rock salt obtainable in the Punjab possesses a reddish tinge due to the presence of small amount of iron oxide.

Pure sodium chloride is a transparent, crystalline substance. At 0°C 35·5g. saturates 100g. of water. The pure subtance is not deliquescent, but the ordinary kitchen variety cakes together in rainy season by absorbing moisture from the air because of the presence of deliquescent magnesium and calcium chlorides as impurity.

(*b*) *Sodium carbonate* : It is used in preparing many substances such as caustic soda, glass, soap etc. It finds applications in textile industries. It is used for water softening and as a reagent in the laboratory.

It is a compound made up of three elements namely sodium, carbon and oxygen. Its formula is Na_2CO_3. On evaporation of its aqueous solution and cooling it crystallises as $Na_2CO_3.10H_2O$. This hydrated salt is a household alkali and is known in the market as 'washing soda.' The decahydrate loses water readily in air forming a white powder of the monohydrate $Na_2CO_3.H_2O$. The method now in use in all countries for preparing soda ash Na_2CO_3 is ammonia soda process sometimes called Solvay process after the name of the discoverer Solvay, the Belgian chemist.

(*c*) *Caustic soda* : It is a deliquescent. white solid. It is a strong alkali and readily attacks skin. Metallic sodium is obtained by electrolysis of fused caustic soda. It comes into the preparation of soap, paper and artificial silk. It is also employed in the refining of petroleum. Moreover, it finds use as a laboratory reagent.

It is composed of three elements : sodium, hydrogen and oxygen and its molecular formula is NaOH.

Two methods are mainly .used for manufacturing the substance.

Aqueous solution of sodium carbonate mixed with milk of lime (in slight excess of the theoretical value) is heated by steam, when calcium carbonate is thrown out of the solution as a precipitate and caustic soda remains in solution. *Or*, brine (a saturated solution of pure common salt) is electrolysed and this is the chief commercial method today in countries where electric energy is cheap.

(*d*) *Lime* : Lime, the cheapest basic substance, is a compound of calcium with oxygen and its formula is CaO. Its chemical name is calcium oxide and is also known as quick lime.

Numerous are its applications. It has a strong affinity for water and that is why it is used for absorbing water vapour. When water is sprayed over the lumps of quicklime, much heat is given out, steam evolves with a hissing sound, the lumps increase in volume and ultimately crumble into powder, which is named as slaked lime : $CaO+H_2O=Ca(OH)_2$. It is used as a building material and for preparing bleaching powder, caustic soda, and in tanning. The slaked lime on shaking with water gives *milk of lime* and the decanted clear liquid is *lime water*, clean lime water is a remedy for infant's diarrhoea. *Sodalime* made by slaking quicklime with caustic soda is used as absorbent for many gases such as carbon dioxide, sulphur dioxide, hydrogen chloride etc.

Quicklime is made in our countries either by heating limestone, calcium carbonate ($CaCO_3$) or burning hard shells of oysters etc. in brick built kiln. Shells of these animals also consist of calcium carbonate. Heat decomposes the carbonate into calcium oxide and carbon dioxide :

$$CaCO_3 \rightleftharpoons CaO+CO_2.$$

(*e*) *Ammonium sulphate* : Ammonium sulphate is a transparent crystalline solid. Its formula is $(NH_4)_2SO_4$. It is highly soluble in water. It is one of the nitrogenous fertilisers by the application of which to the soil an increased production of the crop can be achieved. It is a salt and finds use also in the preparation of other ammonium salts.

It may be prepared by passing ammonia through a 60% solution of sulphuric acid : $2NH_3+H_2SO_4=(NH_4)_2SO_4$.

(*f*) *Copper sulphate* : Cupric sulphate is generally known simply as copper sulphate and it is the most important cupric salt. It forms large blue crystals $CuSO_4 . 5H_2O$. It may be prepared by dissolving cupric oxide in dilute sulphuric acid. But on a large scale it may be obtained by blowing air through scrap copper kept moist by a spray of warm dilute sulphuric acid :

$$2Cu+2H_2SO_4+O_2=2CuSO_4+2H_2O.$$

It is an efflorescent solid ; the pentahydrate crystals lose water in air and pass on to a pale blue powder of $CuSO_4 \ 3H_2O$. At 220 - 260° it becomes almost anhydrous. Anhydrous copper sulphate is a white powder, which readily absorbs water and becomes blue again. This change is utilised in detecting the presence of water in a gas or non-aqueous liquid. Copper sulphate is used as a germicide and fungicide in agriculture. It is used in electroplating and also finds use in preserving hides and woods.

(g) *Bleaching powder* : It is dirty white powder, the composition of which is undoubtedly a complex one. It is commonly represented simply as $Ca(OCl)Cl$, which however is the best approximate one. It is obtained by the action of chlorine of nearly dry slaked lime :

$$Cl_2+Ca(OH)_2=Ca(OCl)Cl+H_2O.$$

It possesses a suffocating, unpleasant strong smell. Moist carbon dioxide decomposes it and chlorine is set free thereby. That is why it is to be preserved in air-tight bottles or tins.

It is used for manufacturing chloroform. Because of its strong oxidising power it is widely used as a disinfectant. As a bleacher it finds use in paper and textile industries, but now-a-days it is being largely replaced by liquid chlorine.

(h) *Glass* : The Egyptians discovered the art of preparing glass from potash extracted from vegetable ashes. Though we are decidedly more familiar with the 'glassy' or 'vitreous' state of silicates in the form of ordinary window glass, the state is by no means limited to silica and silicates.

Ordinary glass is a homogeneous mixture and not a pure substance. It is not possible to express its composition by a definite formula ; its composition varies within a wide range of limits, which is determined by the kind and quality desired by the producer. Silicon oxide is, for all practical purposes, a common constituent of almost all glasses. The other constituents are dioxides of alkali metals (e.g , sodium, potassium etc.) and alkaline earth metals (e. g., calcium, magnesium etc.) These in the combined state as silicates (e. g., sodium silicate, calcium silicate) remain dissolved in each other and in excess of silica. Glasses meant for special purposes are made by varying the constituents and or their proportions. Thus, for instance, cobalt oxide, chromium oxide etc. make the glass coloured.

With regard to the arrangement of atoms glasses resemble liquids. Most molten substances crystallise at their respective freezing points. Molten glass, if however be cooled, does not crystallise, and although it acquires rigidity, it is not a solid in the truest sense. of the term. This rigidity or hardness as it is called is only superficial, it is such a super-cooled liquid that it cannot move freely. Hence a glass may be thought of as a highly viscous super-cooled liquid that apparently resembles a solid (amorphous).

It is used in doors and windows, for preparing laboratory glass wares such as test tubes, beakers, flasks and the like. It also comes into the preparation of lenses, prisms, electric bulbs etc., and in giving glazes on chinaware and enamels on iron kitchen utensils.

Questions

1. What do you mean by : 'Allotropy and allotropes' ?
   Write what you know about the allotropes of carbon and phosphorus.

2. What are the sources of boron and sulphur? Mention some of the uses of sulphur.

'White and red phosphorus are nothing but the allotropes of one and the same element phosphorus'—Discuss.

3. Write in short what you know about the nature, sources and uses of each of the following:

Common salt, washing soda, bleaching powder and glass,

4. State two uses of each of the following substances:

Caustic soda, copper sulphate and ammonium sulphate.

Sample questions for objective type tests

A. Completion type:

The ordinary kitchen variety of common salt
cakes together by absorbing—(a) from the air —(a)
in rainy season because of the presence of—(b) —(b)
calcium and magnesium chlorides as—(c) —(c)

B. Recall type:

(i) The white anhydrous copper sulphate turns into the — hydrated one by absorbing water. —

(ii) Bleaching powder is a good disinfectant owing to its strong — power. —

(iii) The rigidity of glass is only superficial, it is really a highly — supercooled liquid. —

CHAPTER FOUR

METALS AND THEIR ALLOYS

From time immemorial some substances now known as metals are in the service of man. But most of the metals occur as their compounds in nature. Few only occur also native. Gold, for example, usually occurs free in nature. Copper, silver, tin etc. are sometimes found to occur free. All these naturally occurring compounds or materials devoid of life and formed by the processes found in nature are termed *minerals.* But minerals need not necessarily be compounds. Man possesses no directing power in their formation and they occur in water, soil or rocks in the earth. Minerals from which a particular metal can be profitably extracted are called *ores* of that metal.

4-1. Iron

We are blessed with huge source of iron and of metals iron is second to aluminium in abundance. It makes up about 4·2% of earth's crust by weight. It occurs in green plants and haemoglobin of blood. Very little of it is found free, as meteorites sometimes consists of metallic iron. Chief iron bearing minerals are noted below :

(i) Oxide (a) Megnetite, Fe_3O_4
(b) haematite—red (Fe_2O_3),
brown ($2Fe_2O_3.3H_2O$)
(ii) Carbonate : Spathic iron ore, $FeCO_3$
(iii) Sulphide : Iron pyrites FeS_2.

Haematite is considered to be the chief ore of iron.

Properties : Pure metal has a lustre of its own. It is soft and white. It may be hammered into sheets and drawn into wires. Pure metal melts at 1539° and its Sp. gravity is 7·9.

Dry air does not attack it, but in moist air it rusts. Red hot iron burns in oxygen forming Fe_3O_4 : $3Fe+2O_2=$

Fe_3O_4. Red hot iron decomposes steam and is itself oxidised to ferrosoferric oxide : $3Fe+4H_2O \rightleftharpoons Fe_3O_4+4H_2$. It dissolves in dilute hydrochloric or sulphuric acid, when hydrogen is evolved and ferrous salt formed : $Fe+2HCl=FeCl_2+H_2$. For reactions with nitric acid see pages 22-24. For all purposes iron is not attacked by alkali solutions.

There are three varieties of iron : Cast iron, wrought iron and steel, of which wrought iron is the purest one containing only 0·12—0·25% of carbon. Cast iron contains about 2·2—4·5% of carbon, which makes it hard and brittle, while steel stands midway containing 0·15—1·5% of carbon.

Uses : The principal utilisation of *cast iron* is in producing steel and (to some extent) wrought iron. It is used for making fire grates, railings, lamp posts etc. which are usually cast in moulds and hence the name. *Wrought iron* is used in making iron plates, sheets, wires, nets etc. It is also employed for making electro-magnet. The most widely used variety, however, is *steel*, which finds its uses in the construction of bridges, railway lines, ships, motor cars and for making articles such as razors, saws, watch springs, household utensils etc.

4-2. Copper

Copper is one of the few metals that occur native and that is why it has been known since prehistoric times. The name copper is derived from Latin cuprum ; which refers to its production by the Romans in the island of Cyprus. In fact Latin 'aes cyprium' (Cyprian copper) later on came to be cyprium and cuprum. A few important minerals of the element are listed below :

Oxide : Cuprite, Cu_2O.

Sulphide : Copper pyrites, $CuFeS_2$; Chalcocite, Cu_2S.

Copper pyrites is the commonest ore of the metal.

Properties : Copper possesses a characteristic red colour ; m.p. 1083°C. It is a soft, ductile and malleable metal and an excellent conductor of heat and electricity.

In ordinary air it tarnishes superficially only, a protective coating of oxide or sulphide is formed thereby. But in the air of towns and cities a green film or basic sulphate is formed. If heated for a long time in air, copper oxide CuO is formed, and at a temperature above 1100°C this oxide changes to cuprous oxide : $2Cu+O_2=2CuO$, $4CuO=2Cu_2O+O_2$. Copper is not attacked by cold non oxidising acids such as hydrochloric or dilute sulphuric acid. In presence of air copper slowly dissolves in dilute sulphuric acid : $2Cu+2H_2SO_4+O_2=2CuSO_4+2H_2O$. It dissolves readily in nitric acid, when copper nitrate and reduction products of nitric acid are formed (P. 23.) Fused alkali attacks the metal changing it into cupric oxide. Copper dissolves in ammonium hydroxide in presence of air.

Uses : After silver, copper is the best conductor of electricity and is very widely used in electrical implements. Various alloys of copper such as brass (copper and zinc), bronze (copper and tin) etc. are in much demand. It is also used for coinage and ornamental works.

4·3. Magnesium

Pure magnesium was first obtained by Brutus Bussy, the French physician in 1829. Magnesium does not occur free in nature. In the combined state it is not only widely distributed but also plentiful. **Among the** important are :

Carbonate : *Magnesite*, $MgCO_3$; *Dolomite*, $CaCO_3$, $MgCO_3$. Salt deposits at Stassfurt in Germany contain chloride and sulphates e.g., *Carnallite*, KCl, $MgCl_2$, $6H_2O$, *Kieserite*, $MgSO_4$, H_2O etc. Besides, the minerals *Talc*, *Absestos* etc. contain magnesium. It is an essential constituent of plant and animal tissues. Sea water also contains magnesium compound.

Properties : Magnesium is a silver-white, soft metal of low sp. gravity (1·74). Its m.p. and b.p. are 651° and 1100°C respectively.

Magnesium tarnishes in moist air, as it soon gets coated with a thin film of its oxide. The metal, if heated in air, burns with an intense white light and the product is a mixture containing mainly magnesium oxide and a little of its nitride : $2Mg + O_2 = 2MgO$; $3Mg + N_2 = Mg_3N_2$. But only magnesium oxide is formed in pure oxygen. Magnesium powder decomposes hot water evolving hydrogen. While magnesium amalgam decomposes cold water and the heated metal burns in steam : $Mg + H_2O = MgO + H_2$. Magnesium dissolves in all the three dilute acids—hydrochloric, sulphuric and nitric ; but it does not dissolve in alkalis. The metal, it is to be noted, liberates hydrogen from nitric acid, if and when the latter is cold and very dilute. $Mg + 2HNO_3 = Mg(NO_3)_2 + H_2$.

Uses : It is used in flash light photography and for making fire works. It is a constituent of many light alloys : magnelium (Mg+Al), duralumin (Al+Cu+Mg+Mn), electron (Mg+Zn+Cu) etc. some of which are particularly adapted to aircraft construction. It finds use as a deoxidant and in organic syntheses.

4-4. Aluminium

Aluminium is the most abundant metal in earth's crust in which it occurs to the extent of about 8%. Its compounds are widely and plentifully distributed. Some better known are : *Corundum*, *Diaspore*, *Bauxite* and *Gibbsite*—all are oxides $Al_2O_3.nH_2O$, values of n are 0, 1, 2 and 3 respectively i.e., corundum is anhydrous. Some precious stones such as ruby, sapphire etc. used as gems are aluminium oxide with small amount of other substances that impart colour to them. Besides, *Cryolite* Na_3AlF_6, *Kaolin* $Al_2O_3, 2SiO_2,.2H_2O$ are important aluminium bearing minerals. But the chief ore of the metal is bauxite.

Properties: Aluminium, when pure, is a silver white metal. It is both malleable and ductile. It is a metal of low density, 2·7 gm. per c.c. and melts at 659·8°C. It is a good conductor of heat and electricity.

It remains almost unaffected in pure air or water; a thin transparent film of oxide that protects the metal from further action is being formed. Aluminium powder, if heated in air, burns with a bright flame; aluminium oxide and nitride being formed: $4Al+3O_2=2Al_2O_3$, $2Al+N_2=2AlN$. Sea-water and some salt solutions attack the metal strongly, although it is only superficially attacked by pure water. Moreover, aluminium amalgam decomposes cold water with the evolution of hydrogen: $2Al+6H_2O=2Al(OH)_3+3H_2$. It dissolves readily in dilute or concentrated hydrochloric acid: $2Al+6HCl=2AlCl_3+3H_2$. Dilute sulphuric acid scarcely attacks the metal, which, however, reacts with concentrated sulphuric acid when heated. Aluminium dissolves in the acid which is reduced to sulphur dioxide. Nitric acid, dilute or concentrated, is almost without any action on pure aluminium. Caustic alkali dissolves the metal readily with the evolution of hydrogen and formation of aluminates: $2Al+2NaOH+2H_2O=2NaAlO_2+3H_2$. Hot and concentrated solution of sodium carbonate dissolves aluminium: $2Al+Na_2CO_3+3H_2O=2NaAlO_2+CO_2+3H_2$.

Uses: It is used for making various utensils. As a conductor the metal competes with copper, conductivity together with low cost has led to its extensive use in electrical implements. Aluminium powder mixed with linseed oil is a pigment. Its thin shining foils are used for wrapping cigarettes, chocolates etc. It is used for coating the mirrors of special optical appliances owing to high reflecting power of polished aluminium for light, especially ultraviolet one. Mixture of aluminium powder and iron oxide—known as thermite—is used for welding purposes such as mending broken rails. Some of its alloys (such as duralumin) are almost as strong as mild steel. But it is very light and it is this combination of strength and lightness, together with low price makes them suitable for aircraft construction.

4-5. Zinc

Only in traces zinc is found in free state in Australia. In the combined state it is abundant and widely distributed. Better known minerals are :

(i) Oxide : *Zincite*, ZnO ; *Franklinite*, ZnO, Fe_2O_3
(ii) Carbonate : *Calamine*, $ZnCO_3$
(iii) Sulphide : Zinc blende, ZnS, which is the chief ore of the metal.

Properties : Zinc is a bluish white metal of sp. gravity 7·1. It is somewhat brittle at ordinary temperature. But in between 100°—150°C it is malleable and ductile, when sheets or wires can be made. It melts and boils at 419°C and 920°C respectively and its vapour is monatomic.

In moist air a crust of basic carbonate $ZnCO_3, 3Zn(OH)_2$ is formed. It burns with a green flame, when ignited in air, yielding zinc oxide : $2Zn+O_2=2ZnO$. Pure zinc is not attacked by water. But commercial zinc or zinc coated with copper decomposes boiling water. Red hot zinc decomposes steam, but this reaction is reversible and dry hydrogen reduces the oxide above 450° to metallic Zinc : $Zn+H_2O \rightleftharpoons ZnO+H_2$. Commercial zinc dissolves readily in hydrochloric or dilute sulphuric acid evolving hydrogen $Zn+H_2SO_4=ZnSO_4+H_2$. Its reaction with nitric acid has already (Pp. 23-24) been discussed. The metal dissolves in hot caustic soda and caustic potash forming zincate and evolving hydrogen : $Zn+2NaOH=Na_2ZnO_2$ (sodium zincate)$+H_2$.

Uses : Large quantities of zinc are used to coat iron sheet and various household articles in protecting them from corrosion. Zinc is a part of many important alloys such as brass (Cu+Zn), German silver (Cu+Zn+Ni), etc. The metal is an important component of dry cells. Zinc dust and granulated zinc are good reductants. Zinc oxide finds use as a pigment.

4-6. Lead

Lead has been known from very early times and Roman ruins in Europe bear ample evidences of lead water pipes. Traces of native lead are said to occur in some places such as Sweden. But in the combined state it is widely distributed. Its chief ore is *galena* PbS, which generally remains associated with zinc blende and other impurities, and usually contains 0·01—0·1% of silver. Other lead bearing minerals are *cerussite*, $PbCO_3$; *anglesite*, $PbSO_4$ etc

Properties : Pure lead is a very soft metal possessing a silver-white lustre. But it is usually bluish-grey in colour and its hardness is due to the presence of foreign substances like copper, antimony etc. It leaves behind a black mark when drawn across a paper. It is a heavy metal of density 11·34 gms/c.c., lead melts at 327°C.

The metal tarnishes in moist air due to formation of a thin film of basic carbonate which protects the metal from further action. Dry air is without any action on lead. But lead monoxide is formed when fused lead is heated in air and at 450—470° the monoxide passes on to red lead, Pb_3O_4 : $2Pb+O_2=2PbO$; $6PbO+O_2=2Pb_3O_4$. Lead is not attacked by pure water free from oxygen, but at a very high temperature steam is slowly decomposed by the metal. Water containing dissolved air, however, attacks the metal forming lead hydroxide, the solubility of which though small is quite appreciable. But hard water containing dissolved oxygen is almost without effects on lead. A coherent, insoluble thin film of lead carbonate and/or sulphate formed on reaction between the metal and soluble carbonates etc. present in hard water protects the metal from further reaction. Thus, lead though a cumulative poison, drinking water, which is hard may safely be conveyed through pipes made of it. The metal dissolves readily in hot dilute nitric acid with the liberation of nitric oxide: $3Pb+8HNO_3=3Pb(NO_3)_2+2NO+4H_2O$. The metal is not attacked by dilute hydrochloric or dilute sulphuric acid. In presence of air the metal is rapidly attacked even by such week acids as acetic and carbonic acid.

Uses: It is used for making water carrying pipes, in the sheathing of electric cables. Lead is in demand for preparing bullets, the plates of accumulator and the chambers of old fashioned sulphuric acid works. The metal is a constituent of some important alloys such as solder ($Pb+Sn$), type metal ($Pb+Sn+Sb$) etc. Lead in the form of its compounds finds varied applications—use of litharge in preparing flint glass and mixing lead tetraethyl with petrol for automobiles may be cited for illustrations.

4-7. Mercury

As the metal occurs native, though in small quantities, it excited the interest of ancient natural philosophers and has therefore, been known since very early times. Its chief source is, *cinnabar*, mercuric sulphide, HgS, which is found chiefly in Spain, in appreciable amounts in Italy and in smaller amounts in America, the U. S. S. R., China and Japan.

Properties: Mercury is a silver-white liquid metal. In fact mercury is the only metal, which is liquid at room temperature. It is the heaviest liquid known and has a sp. gravity of 13·59. It freezes at −38·9° and its b.p. is 357°. The metal is an excellent conductor of electricity.

Pure mercury is not attacked by air or oxygen; it does not tarnish in air, lustre is retained indefinitely. When heated in air mercuric oxide is formed and this oxide on strong heating decomposes into metallic mercury and oxygen: $2Hg+O_2\rightleftharpoons 2HgO$. Water, even in the form of steam is without effects on mercury. Hydrochloric or dilute sulphuric acid or alkalis are without action on the metal, which however dissolves readily in dilute nitric acid forming mercurous nitrate and oxide of nitrogen :

$$6Hg+8HNO_3=3Hg_2(NO_3)_2+2NO+4H_2O.$$

Mercury vapour is highly poisonous

Uses : It fluidity, high density, excellent conductivity, uniform expansion for rise of temperature, low vapour pressure and unreactive character make it a highly useful substance and it is used in the construction of thermometers, barometers and many other scientific instruments. Mercury is a constituent of many Ayurvedic drugs and of alloys known as amalgams. It is also used in the manufacture of mercury fulminate for detonators

4-8. Alloys and Amalgams

An *alloy* is a metallic material retention of metallic properties) formed from two or more elements. It is generally obtained by allowing the molten mixture of the constituent elements to solidify on cooling. Pure gold is too soft to be used in coinage or ornaments. It is usually alloyed with copper or silver or both Silver makes the colour paler, while copper makes it more red. *Brass*, an alloy of copper and zinc prepared by melting the constituent metals together. It is harder than copper and its m p. is lower than that of copper. It is used in making various household utensils, rods, tubes, locks, taps etc. *Bell metal*, an alloy of copper and tin is made by gradually adding copper to molten tin. It is widely used for domestic utensils and for making bells.

Alloys of mercury are called *amalgams* and many metals dissolve in mercury forming amalgams. Many alloys of mercury and other metals are liquid. Hence, it is not necessary for an alloy to be solid. Many amalgams contain definite compounds e.g., $NaHg_2$, Au_2Hg etc. Some metals (e.g., gold) are extracted through the process of 'amalgamation'. Tin amalgam is used as the reflecting surface in cheap quality mirrors. Sodium amalgam is a convenient reducing agent. Silver amalgam is used in dentistry for filling teeth

Questions

1. What is the difference between a mineral and an ore ? Name the chief ore of iron. Describe in brief the properties of iron. State what you know about its uses.

2. Write in brief what you know about the occurrence, important properties and the principal uses of copper.

3. Mention the chief ore, two chemical properties and two important uses of each of the following metals :

(a) Zinc, (b) aluminium and (c) lead.

4. What do you mean by 'alloys and amalgams' ?

What is the chief source of mercury ?

Write what you know about the properties and uses of mercury.

5 (a) Under what conditions does water react with each of the following metals :

(i) magnesium, (ii) iron and (iii) aluminium ?

Give equations stating the changes that might have taken place.

(b) Describe with equations the changes that occur in the following processes :

Zinc and aluminium are separately heated with conc. solution of caustic soda.

Sample questions for objective type test

Alternate response type

Yes or No type

(i) Can magnesium liberate hydrogen from cold and very dilute nitric acid ? —

(ii) Is bell metal an amalgam ? —

(iii) Can the lead pipes be used for conveying drinking water, which is hard ? —

(iv) Is mercury the only metal, that is liquid at ordinary temperature ? —

CHAPTER FIVE

ORGANIC COMPOUNDS

In days of yore organic substances like alcohol, fats, oils, starch etc. were known. But men were not familiar with their chemistry and in fact organic chemistry as a science rational and methodical is not of long standing. In 1675 Lemery classified the compounds derived from nature into three groups in accordance with their sources—Vegetable, animal and mineral. But Lavoisier by means of his epoch-making experiment made it plain that all vegetable and animal matters had in them at least such elements as carbon and hydrogen and frequently nitrogen. So vegetable and animal products are greatly akin. Later on, in some cases again the same compound was found to exist in the composition of both vegetable and animal matters. Hence it is evident that two classes of compounds are not essentially different. Viewed in this light, it is clear that a modification of Lemery's classification is imperatively necessary. So about 200 years ago that is in the latter part of the 18th century the word 'organic' was coined in chemical terminology to differentiate distinctly the products of living organisms (plants and animals) from those of the non-living world. The compounds of non-living origin were, therefore, termed 'inorganic'.

It is a wonder that organic compounds with diverse characters are all derived from a selected few of the large number of elements known. The production of these compounds was so far beyond the scope of ones creative abilities *i.e.*, it was not possible to form them artificially. As a result the then men of science were of opinion that it was impossible to produce organic compounds without the intervention of what was called 'vital force' existing in living cells.

It was Wöhler who first raised his voice of protest against the theory of vital force. In 1828 he noticed that the evaporation of a solution ammonium cyanate converted a portion of inorganic salt into urea, decidedly an organic compound This is an end product of animal metabolism, occurs in the urine of mammals and was hitherto obtained only from animal sources. Though in retrospect this experiment of Wöhler appears to provide a synthesis of organic compound demonstrating the continuity between organic and inorganic chemicals, yet the conclusion was then not as obvious as it is now. At the time it gave only a shock to the aforesaid theory but could not oust it altogether. Since that time many syntheses followed, one of the earliest being that due to Kolbe, who in 1845 obtained acetic acid in the laboratory without the aid of vital force. By 1850 the vitalistic theory was entirely dead. Thus the retention of the two terms organic and inorganic would appear unnecessary. Yet the designations are still there, the word organic has lost much of its original significance and it is clearly a case of distinction without any real difference. The distinctive features that demand a separate treatment are as follows :

(i) The so called organic compounds invariably contain carbon and the chemistry of carbon compounds is termed organic chemistry, though the element carbon, its oxides, carbonates etc. are included in the subject matter of inorganic chemistry. What was once organic chemistry is now known as chemistry of carbon compounds.

(ii) Carbon compounds are more numerous than those that do not contain carbon. It becomes merely convenient to study them in a separate division of chemistry.

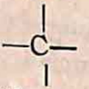
(iii) Viewed in this light it may seem surprising that though the compounds containing hydrogen are even more numerous than are those of carbon, yet we have no separate or distinct branch of chemistry dealing with the compounds containing hydrogen. The crux to the problem lies in the unique valence character of carbon. Carbon atoms can hook on to one another by covalent linkages without any known limit so that the potential number of organic compounds is virtually limitless This property known as catenation is not found to such a degree in any other element.

Scope : Numerous are the achievements of organic chemistry ; the scope of organic chemicals is vast indeed. From carbohydrate to protein, from paper to nylon, from rubber to bakelite, from quinine to penicillin, etc. are nothing but organic chemicals. They are eaten as foods. We take in carbohydrates such as rice, wheat, potato, sugar, etc. as food. Our food includes proteins e.g., fish, meat, egg etc, and fatty matters such as butter and vitamins as well. They are worn as clothes and used as drugs. To mention a few nylon and terylene are synthetic fibres that surpass the natural ones in durability and aesthetic value. Quinine fights malaria. Urea stibamine is a specific remedy for Kala-azar. Iodoform is a good disinfectant. The drugs penicillin, streptomycin, chloromycetin etc., the wonders of modern times are combating the dreadful diseases such as pneumonia, tuberculosis, typhoid, etc., that take a heavy toll of human lives every year and thus the drugs have come to the relief of the suffering millions. The discovery of chloroform, either and the like that are used as anaesthetics has removed the horrors of surgery. They include fertilisers and insecticides. It is hoped that by proper utilisation of the knowledge acquired by unremitting research the food problem of the world will be solved in future. The advent of petroleum and the like ushered in a new era in our ever advancing civilisation.

The study of life processes in one of the most important applications of organic chemistry. A thorough and careful examination of the tissues, various secretions, the other constituents and their nature or products of plants and animals is based upon this branch of chemistry. In fact, organic compounds constitute most of the materials associated with living organisms. The chief source of carbon in living beings is carbon dioxide which is converted into simple chemicals in green plants through the process of photosynthesis. These simple chemicals are converted into multitude of natural products by metabolic processes of plants and animals. To understand the digestion and assimilation of food requires the knowledge of basic principles of organic chemistry. The digestive organs provide the necessary enzymes and maintain the right condition of warmth, acidity, etc. for the proper functioning of the latter. The food gets digested through various chemical changes. The undigested foodstuffs are periodically expelled by voluntary muscular action. The importance of organic reaction here will be evident from an example. In presence of enzymes proteins of food materials are converted into simpler compounds, amino acids, which repair and rebuild the body cells. The function of enzyme is catalytic. That the vitamins are organic compounds have already been stated. These substances in very minute amounts are essential for the normal growth and proper nourishment of the body. Deficiency of these material in our diet makes the body susceptible to various diseases. Hormones are organic compounds. They exert a regulatory influence on body functions. Insulin, a hormone secreted by pancreas is essential for the metabolism of carbohydrates and deficiency of the substance leads to the disease diabetes mellitus. A hormone again can turn a normal man into a lunatic one. It is remarkable that some hydrocarbons may induce the dreadful disease cancer. That the various facts comprising the life process and many more mysteries of nature can largely be explained on the basis of organic chemistry are now understandable. Hence, starting from basic needs of man there is hardly any field in which this branch of chemistry has no direct or indirect applications.

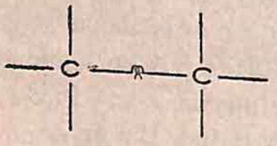
Carbon linkages and classification of organic compounds

Naturally we are now confronted with the question of how it is possible for carbon atom to form so many different compounds of such wide variety. The solution to the problem is found in the theory relating to carbon linkages as proposed by the German scientist Kekule, the father of modern organic chemistry. Although a brief reference to the theory has already been made a proper understanding of it demands its discussion in a little more detail. The main postulates of the theory are : (i) Carbon has usually the constant valency of four, (ii) atoms of carbon have the power to combine with one another, without any known limit. The atoms of most of the elements on the other hand unite with the atoms of other element in accordance with their valencies and the few elements namely silicon or nitrogen that may unite with itself can do the same to a limited extent only. Graphic representation here will be helpful for understanding it. Affix short lines to the symbol of the element to indicate the valency bonds, one line for every valence and arrange them in the three ways as follows :

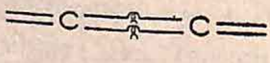


$$-\overset{|}{\underset{|}{C}}- \qquad =C= \qquad -C\equiv$$

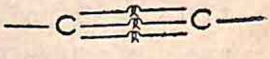
Consider the lines as hooks and imagine that one hook can hold one and one hook only. Hook the above figures together, two by two. Three possible arrangements are :



Single bond

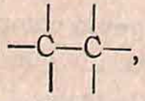


Double bond



Triple bond

Thus the carbon atoms can unite by single, double or triple bonds. One valency of each of the atoms concerned is utilised in establishing a linkage. This is shown by drawing a full line in between the atoms concerned. One line represents a single bond, two a double bond and three a triple bond.



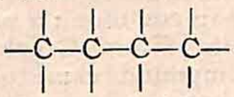
$$-\overset{|}{\underset{|}{C}}-\overset{|}{\underset{|}{C}}-, \qquad =C=C=, \qquad -C\equiv C-$$

According to modern theory a linkage or valence bond of Kekulé involves sharing of one pair of electrons between the atoms. Similarly a double bond implies sharing of two pairs and a triple bond three pairs between the atoms. That is to say that carbon atoms unite with each other by covalent linkage. Carbon may unite in the same fashion with atoms of other elements too.

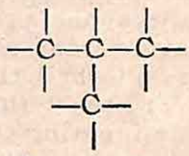
$O=C=O$ Carbon dioxide

$H-C\equiv N$ Hydrogen cyanide

We have so far taken two carbon atoms only in our discussion. Not only two but without any known limit carbon atom may unite with itself in the similar fashion to form **open** chains of carbon, which may be *straight* or *branch* and thus the existence of many different compounds are accounted for.

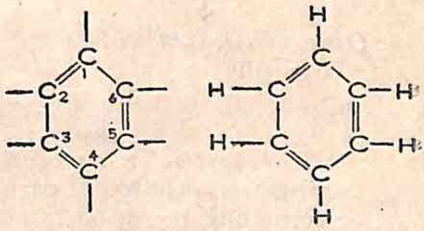


Open and straight



Open and branched

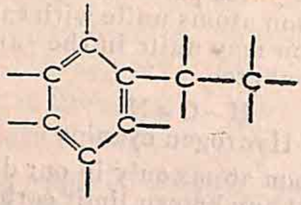
But many more carbon compounds such as benzene and the like are there whose formulae would not line up in this kind of arrangement. It was again Kekule, the man endowed with keen intuitive faculties solved the problem. The solution, it is said, came to him in a dream. Once after toiling for the whole day with long chains of carbon atoms he felt drowsy, while sitting before the fire in the evening. In his dream the chains turned into snakes, twisting and twining. When one of the snakes in doing so seized its own tail all of a sudden and formed a ring, the idea of cyclic structure came to the master mind. Thus a carbon atom (acting as the mouth of a snake) may grasp another atom farther away (like the tail) from the former in the chain forming a **ring** or **closed chain** or **cyclic structure**.



Closed chain

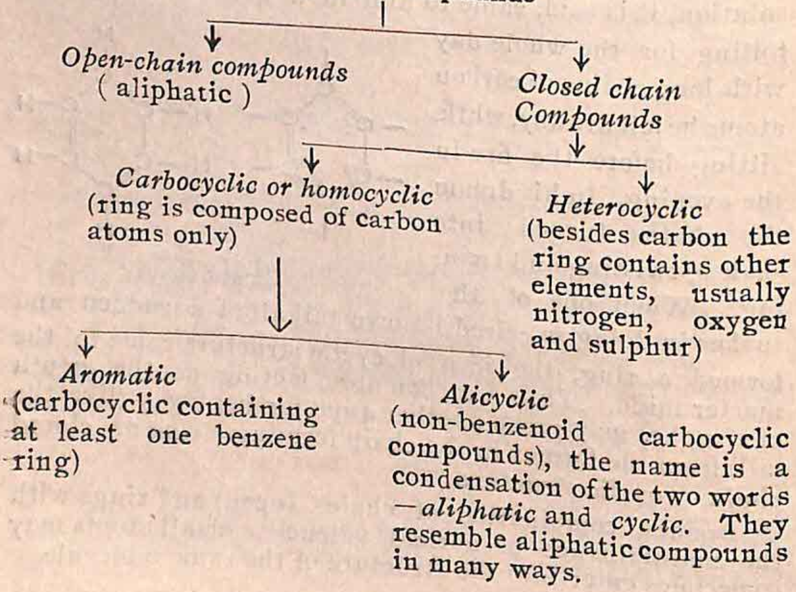
Besides, combination of chains (open) and rings with the maintainance of normal valencies of all atoms may sometimes enter into the structure of the same molecule.

Chemists in the early days classified the organic compounds into two broad divisions; (i) *aliphatic*, which includes fats such as tallow, etc. and compounds related to them. The word 'aliphatic' is derived from Greek 'aliphos' meaning fat. (ii) Besides, early in the development of organic chemistry some other compounds were obtained from natural sources such as resins, balsams etc. These compounds could not be fitted into the then known aliphatic compounds. Though the structures of the compounds were not known, they were found to possess one property in common: a property of having a flavour-fragrant smell. From Greek 'aroma' meaning fragrant smell, these compounds came to be known as *aromatic*. The two terms aliphatic and aromatic are still retained for designating the two main divisions of organic chemistry. But the fatty character or the aroma of a compound is no longer considered to be the basis of its classification. Any compound having an open-chain structure is now classified as aliphatic, while the term aromatic is reserved for benzenoid compounds. A brief summary of the more detailed classification is given below:



Combination of open and closed chain

Organic Compounds



Open-chain compounds (aliphatic)

Closed chain Compounds

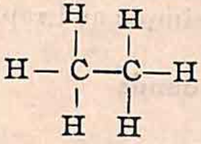
Carbocyclic or homocyclic (ring is composed of carbon atoms only)

Heterocyclic (besides carbon the ring contains other elements, usually nitrogen, oxygen and sulphur)

Aromatic (carbocyclic containing at least one benzene ring)

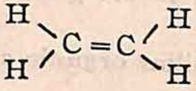
Alicyclic (non-benzenoid carbocyclic compounds), the name is a condensation of the two words —*aliphatic* and *cyclic*. They resemble aliphatic compounds in many ways.

It is to be noted that in a molecule if all the carbon atoms concerned are joined to one another by single covalent linkages, the compound is said to be saturated. If one the other hand, the molecule contains at least one such pair of carbon atoms as are linked with one another by two or three covalent bonds, the molecule is an unsaturated one. Thus ethane, for example, is a saturated compound, while ethylene and acetylene are unsaturated. The structural formulas of these compounds are given below :



$$\begin{array}{ccccccc} & & H & & H & & \\ & & | & & | & & \\ H & - & C & - & C & - & H \\ & & | & & | & & \\ & & H & & H & & \end{array}$$

(ethane)



(ethylene)

$H-C\equiv C-H$

(acetylene)

Comparison between organic and inorganic compounds.

(i) Organic compounds invariably contain carbon, but the converse is not always true. Organic compounds though large in number and wide in variety contain a few more elements (such as hydrogen, oxygen ; sometimes nitrogen, sulphur, phosphorus and some metals) besides carbon. On the other hand, of the elements known todate a little over hundred each has a place of its own in the case of inorganic compounds.

(ii) Inorganic compounds are usually electrovalent, while organic compounds are covalent.

(iii) Organic compounds are in general soluble in organic solvents and are not usually miscible with water. They are of usually low melting and boiling points and decompose at high temperature. Many inorganic compounds, on the other hand, are soluble in water and usually not miscible with organic solvents. They are usually heat resistant having relatively high melting and boiling points. Many organic and a few inorganic compounds are combustible.

(iv) Many organic compounds are complex molecules, more complex than the inorganic compounds. Their molecules may be very big. Molecular formula of starch, for example, is $(C_6H_{10}O_5)_n$, the value of n may be several hundreds or even thousands. A molecular formula does not always characterise a particular organic compound. A single formula often represents more than one organic compound. Molecular formula of ethyl alcohol is C_2H_6O and another substance called ether having the same molecular formula is also known. Comparable complexity is rarely met with in the inorganic field.

(v) Organic reactions are mostly complex and slow, while inorganic reactions are generally simple and rapid.

A few familiar organic compounds

5-1. Methane, CH_4.

Natural gas is a source of methane. Natural gas issues from many places on the earth's surface. The 'holy fire' of Baku, for example, attracted the attention of fire worshippers as early as 600 A. D. Natural gas occurs in most oil wells. Methane is believed to be responsible for coal mine explosions. The gas evolves from the fissures in coal bed, mixes with air and this mixture explodes with violence on coming in contact with fire. Methane constitutes about 40 p.c. of coal gas by volume. Another name for methane is 'marsh' gas, as it is found in large quantities in marshy land due to bacterial decomposition of organic matter.

One of the methods of large-scale preparation of both methanol and formaldehyde involves the partial oxidation (catalytic) of methane. On heating at 1000°C it decomposes into carbon and hydrogen: $CH_4 \rightarrow C + 2H_2$. The carbon so produced is known as 'carbon black' and is used in making printers' ink and paints and is also in demand in rubber industry. Methane is used in the manufacture of methyl chloride and methylene chloride. Methane also serves as a source of hydrogen; when a mixture of methane and steam is allowed to pass over metallic nickel supported on alumina at 725°C carbon monoxide and hydrogen evolve: $CH_4 + H_2O \rightarrow CO + 3H_2$.

5-2. Ethylene, C_2H_4.

Ethylene constitutes about 4—10 p.c. by volume of coal gas. Large quantities of ethylene are now-a-days obtained as a by-product in the cracking of petroleum. As a result the substance has acquired technical importance and is finding wide applications for the preparation of large number of organic substances.

It is used for artificial ripening of fruits. Mustard gas, a poisonous substance is prepared from it. It finds use in the preparation of solvents glycol, dioxan etc. It is much in demand in manufacture of plastic polythene and alcohol ethanol. It is used as an anaesthetic.

5-3. Acetylene, C_2H_2.

Acetylene in traces occurs in coal gas. It is sometimes formed due to incomplete combustion of some organic substances—it is formed when a Bunsen burner strikes back. Decomposition of some organic substances by heat leads to its formation.

It finds wide applications. It is an illuminant and may be burnt in open jets for illuminating purposes. It is used for producing oxy-acetylene flame. Halogen derivatives of acetylene—acetylene dichloride ($C_2H_2Cl_2$) and tetrachloride ($C_2H_2Cl_4$)—are non-inflammable liquids and are good solvents for oils, fats etc. Acetylene is used for production of a large numbers of chemicals such as acetaldehyde, acetic acid, acetone etc. It is also in demand as a raw material for artificial rubber, synthetic fibre etc.

5-4. Petroleum.

In Latin it means rock oil, petra-rock and oleum-oil. The theory about its origin is still uncertain, the last word is yet to say. According to some it is of vegetable origin while others consider it to be of animal origin. But the theory which is the favoured most is the decomposition of organic materials—both plants and animals. It has been conjectured that plants and various forms of marine life were burried under sand layers where they were subjected to bacterial action and intense pressure and probably high temperature. In the course of ages, thus the decomposition of these organic materials resulted in the formation of a coloured, viscous liquid, which got accumulated in earth pockets capped by rock. This oil is known as mineral oil or petroleum. Underneath the surface of the earth it remains mixed with saline water and sand with overlying layer of natural gas.

Liquid petroleum is a complex mixture, in which saturated hydrocarbons (compounds of carbon and hydrogen only) of open chain structure predominate. The composition of the oil however varies from place to place and no two oils have identical composition. Besides hydrocarbons, the oils also contain small amounts of compounds containing nitrogen, oxygen and sulphur. By fractionation of crude oil different fractions boiling over different ranges of temperature are collected to suit various industrial needs —gasoline or *petrol*, as a fuel for motor and aeroplane ; *kerosene* for lighting and heating purposes ; *gas oil*, used today as a fuel for ships, trains ; *lubricating* oil etc. This petrol or kerosene is no pure substance. They are essentially mixtures of hydrocarbons. Gasoline or petrol is the petroleum fraction that boils between 40° and 200° and the fraction having the range of boiling 175° – 325° is kerosene. Of the two—petrol and kerosene—the latter consists of larger hydrocarbon molecules.

5-5. Ethyl alcohol, C_2H_5OH

As it is the active principle of wine, it is also known as 'spirit of wine'. Ethyl alcohol or ethanol is the most important alcohol and is often called simply 'alcohol'. The various forms of this alcohol with which we are usually familiar are methylated spirit, rectified spirit, absolute alcohol, alcoholic beverages (beer, whisky) etc.

The method of producing this alcohol by fermentation has been in use from prehistoric days. The primitive method was simple and brief. The sugar juice extracted from fruits such as grapes or from any other source is left exposed to air for the nature to do for herself the rest. Concentration of sugar gradually falls and there appears instead an intoxicating principle, what we call alcohol, in the liquid. The influence of a certain type of nitrogenous complex organic compound lies at the root of this change. The method is still in use for preparing beer, brandy, etc. and also as a source of ethyl alcohol. But the above raw materials namely fruit juices are too costly to be used for the production of alcohol on a large scale and hence cheaper raw materials like molasses from sugar factories or starch such as wheat, potatoes, rice, etc depending on the particular country are used for preparing industrial alcohol. But most of the alcohol used in chemical industry is prepared today by hydration of ethylene, which in its turn is produced usually either by cracking of petroleum or by hydrogenation of acetylene. In India alcohol for drinking purpose is being produced in large quantities from mahua flowers, which contain both glucose and fructose ; fermentation leads to formation of alcohol.

$$HC \equiv CH(\text{acetylene}) + H_2 \rightarrow H_2C = CH_2(\text{ethylene})$$

$$H_2C = CH_2 \xrightarrow{H_2SO_4} [CH_3\text{-}CH_2OSO_3H \xrightarrow{H_2O} \underset{\text{ethanol}}{CH_3\text{-}CH_2OH} + H_2SO_4$$

$$\underset{\text{sugar}}{C_6H_{12}O_6} \xrightarrow{\text{fermentation}} \underset{\text{ethanol}}{2C_2H_5OH} + 2CO_2$$

Alcohol containing only 4·4% water (and the rest ethanol) is known as *rectified spirit*. Alcohol of higher concentration cannot be obtained from an aqueous solution of it by fractional distillation, at constant pressure. The mixture containing 95·6% alcohol and 4·4% water boils at a constant temperature and this constant boiling mixture is what we call rectified spirit.

Ethyl alcohol finds wide and varied applications. Apart from its use in beverages, it is used for preparing a large number of organic substances such as chloroform, ether etc.

In pharmaceutical industry it is much in demand as solvent and these solutions are known as tinctures. It is also used as a solvent for paints, varnishes, resins, etc. Mixed with petrol or gasoline it is used as a fuel for motor. Besides, many solid organic compounds are purified by recrystallisation from alcohol.

Alcohol is heavily taxed by the government of a country unless it is denatured to make it unfit for drinking. Alcohol is made undrinkable by admixing poisonous, unpalatable and obnoxious substances with it. Spirit is said to be *methylated* if denatured by methanol or by methanol and other substances, and two kinds of methylated spirits are there : (i) *Industrial methylated spirit* contains about 5% methanol and 95% rectified spirit used for commercial purposes. (ii) *Mineralised methylated spirit* used for domestic purpose contains 9% methanol, 1% petroleum oil and 90% rectified spirit (and a dye). But irrespective of the denaturants used to make the spirit undrinkable, all denatured spirit is usually called methylated spirit. In India alcohol is denatured by pyridine of guaranteed mineral origin together with light caoutchoucine. Denatured spirit being dutyfree sells cheap.

5-6. Chloroform, $CHCl_3$.

Action of chlorine on methane in diffused sunlight leads to formation of chloroform along with other chloromethanes. Besides, partial reduction of carbon tetrachloride with iron filings and water ; heating ethanol or acetone with a paste of bleaching powder (bleaching powder + water), etc. are in use as sources of industrial chloroform, e.g., $CCl_4 + 2H \rightarrow CHCl_3 + HCl$.

It is much in demand in industry as a solvent for fats, rubber, resin, etc. It is used as anaesthetic in surgery and internally as carminative and stomachic. But now-a-days it is being largely replaced by other better anaesthetics such as diethyl ether, etc., Chloropicrin i.e., nitrochloroform (CCl_3NO_2) is an insecticide. Chloroform is also used as a laboratory reagent and as a preservative for decoctions.

5-7. Vinegar.

'Vinegar' means 'sour wine'. It consists essentially of a 6 – 10 percent aqueous solution of acetic acid.

It is produced by the oxidation of ethanol present in low grade (light) wine by air under the influence of bacteria : $CH_3CH_2OH+O_2 \rightarrow CH_3.COOH+H_2O$. The process occurs during the souring of beer or wines.

Because of the introduction of highly efficient methods of fractionation vinegar is today recognised as a source of acetic acid, which is used as a solvent and for preparing acetone, acetic anhydride, etc. Vinegar is used for table purposes, in curing meat and in the preparation of white lead.

5-8. Glycerol, $CH_2OH.CHOH.CH_2OH$.

Animal and vegetable fats and oils such as lard, tallow, cocoanut oil, etc. are compounds of glycerol and various organic acids. These are important sources of glycerol, which is obtained in large quantities as a by-product in soap industry. Glycerol is formed in small amounts in the normal alcoholic fermentation of sugar. Addition of sodium sulphite leads to an increased yield (generally about 25 percent) of glycerol in the process. In some countries, the U.S.A for example, the synthesis of glycerol from propylene has been of late an economic feasibility ; propylene is being obtained from cracking of petroleum.

Glycerol is used as an antifreeze. It finds use in shoe polish, shaving soaps, etc. It is also used in preparing tonics e.g., glycerophosphates, throat paints, etc. Dynamite, blasting gelatin and cordite, the smokeless powder—all require nitroglycerine for their preparation. This so called nitro compound is an ester of glycerol.

5-9. Soaps.

Soap has been in use for many years. No one knows who invented it, but the art of preparing the substance passed down from father to son and mother to daughter.

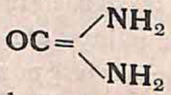
The soap makers of antiquity would extract potash (K_2CO_3) from wood ash and soda (Na_2CO_3) from burnt seaweeds. These were made to react separately with lime to produce potassium hydroxide and sodium hydroxide respectively. Fat was boiled with the alkali thus obtained to prepare soap. Modern practice is very much the same with the only exception that the boiling of a judicious mixture of fats and oils is done in large iron vessel known as soap kettle under steam pressure. In fact, fat or oil or a mixture of the two, whichever is taken, undergoes hydrolysis yielding glycerol and sodium or potassium salts of fatty-acids. It is to be noted here that in the *cold* process hydrolysis is carried out by warm alkali without boiling.

Oil and fat+NaOH (or KOH)→glycerol+sodium (or potassium) salt of fatty acids.

The salts thus obtained are *soaps* and the alkaline hydrolysis is referred to as *saponification*. Salts of sodium and potassium of higher fatty acids (namely stearic, palmitic, etc) are the main constituents of ordinary soaps. Soft soaps are potassium salts. Moreover, soaps contain various fillers such as marble dust and soaps of different varieties contain different substances to suit the purposes for which they are meant. Laundry soap contains soap stone, sodium silicate, etc. and toilet soap contains perfumes and colouring matter.

It is used as a cleansing agent. Special soaps are used for special purposes. Aluminium soap, for example, is used in waterproofing.

5-10. Urea,



$$OC=\begin{array}{l}\diagup NH_2\\ \diagdown NH_2\end{array}$$

Urea is an end product of protein metabolism. The normal individual excretes in the urine to the extent of about 30 gms per day. In 1773 Rouelle discovered the presence of urea in the urine of mammals. It is also present in the blood of mammals and in a number of lower animals —worms and snails.

Large quantities are used as fertiliser and in the making of urea-formaldehyde plastic. It finds use in the preparation of barbiturates used as sedative. Urea stibamine is a specific remedy for kala-azar. The manufacture of hydrazine, which involves the reaction between urea and alkaline sodium hypochlorite is one of the most recent uses of the substance.

5-11. Glucose, $C_6H_{12}O_6$

Glucose is present in honey and various sweet fruits. The name is derived from Greek 'glukus' meaning sweet. It is present in abundance in juice of ripe grapes and its another name is grape sugar. Honey is mainly a mixture of glucose and fructose. It is a normal constituent of blood and found in more than normal amount in the blood of persons suffering from diabetes mellitus. Normal urine contains only a trace of glucose, which is abnormally present in urine in diabetes. In nature it is also found to occur combined with other subtances, e.g., glucosides.

It is used in preparing syrups, Jams, Jellies, etc. and in making wine by fermentation. Pure glucose finds use as a food for invalids. Calcium gluconate is used in calcium deficiency. Glucose is the starting material of a synthetic method for preparing vitamin-C.

5-12. Benzene C_6H_6

Benzene is one of the illuminating principles of coal gas. In 1845 Hofmann isolated it from coal tar and since then it has been an important source of the substance and its derivatives. In recent years petroleum has come to be known as a source of benzene.

It is a good solvent for oils, fats, resins, etc. It is used in dry cleaning. It also finds use in preparing various chemicals such as nitrobenzene, phenol, maleic anhydride, etc. Mixed with petrol it is used as motor fuel.

5-13. Phenol C_6H_5OH

It is commonly known as carbolic acid. It occurs in coal tar. But the amount obtainable from the source is not sufficient enough to meet the world demand to-day. Considerable quantities are now manufactured synthetically.

Phenol is one of the oldest disinfectants. It is also used in preparing drugs (e.g. aspirin), plastic bakelite, explosive picric acid, some dyes, etc.

5-14. Naphthalene, $C_{10}H_8$

Naphthalene is one of those susbtances that are obtainable in large quantities from coal tar. It is also found to occur in small quantities in petroleum from several localities.

Naphthalene is an insect repellent and is used to make moth-balls. It is extremely important as a source material for the manufacture of phthalic anhydride. Phthalic anhydride and phthalic acid find use in the preparation of dyes, plastics, etc. on a large scale. Decalin, a reduction product of naphthalene is a solvent for varnishes, lacquers, etc.

Questions

1. 'Although the terms *organic* and *inorganic* appear to have lost their original significances, the designations are still there'.—Discuss.

2. Write in brief what'you know about the carbon—carbon linkage and the classification of organic compounds based on it.

3. Compare between organic and inorganic compounds.

4. State two uses of each of methane, ethylene, and acetylene.

Write in short what you know about the sources, nature and uses of petrol.

5. What are the sources of ethanol? What do you mean by 'rectified spirit' and 'methylated spirit'?

What are 'tinctures'?

6. What is a 'soap' and what is meant by 'saponification'?

What are the sources of glycerol? Mention some of the uses of the substance.

7. Mention one source and state one use of each of the following substances:

(i) urea, (ii) glucose, (iii) benzene, (iv) phenol and (v) naphthalene.

Sample Questions for objective type tests

Completion type :

Liquid petroleum is a complex—(a), in which—(b) hydrocarbons of—(c) chain structure predominate. The composition of the oil—(d) from place to place and no two oils have—(e) composition.

—(a),—(b),—(c),—(d),—(e).

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